SH11
A13
V.69

CONTENTS

ol, 69, No. 1 January 1971

)EDEL, PHILIP M. In Memoriam—Wilbert McLeod Chapman and Milner Baily Schaefer 1

HLSTROM, ELBERT H. Kinds and abundance of fish larvae in the eastern tropical Pacific, based on collections made on EASTROPAC I 3

IILES, MICHAEL C., JR., and WILLIAM G. PEARCY. Size structure and growth rate of *Euphausia pacifica* off the Oregon coast 79

IOMAS, WILLIAM H., and ROBERT W. OWEN, JR. Estimating phytoplankton production from ammonium and chlorophyll concentrations in nutrient-poor water of the eastern tropical Pacific Ocean 87

UTTER, ROBERT I., and GAIL H. THEILACKER. Ecological efficiency of a pelagic mysid shrimp; estimates from growth, energy budget, and mortality studies 93

)THSCHILD, BRIAN J., and JAMES W. BALSIGER. A linear-programming solution to salmon management . 117

JBROW, DAVID L., and BRUCE R. STILLINGS. Chemical and nutritional characteristics of fish protein concentrate processed from heated whole red hake, *Urophycis chuss* 141

JBROW, DAVID L., NORMAN L. BROWN, E. R. PARISER, HARRY MILLER, JR., V. D. SIDWELL, and MARY E. AMBROSE. Effect of ice storage on the chemical and nutritive properties of solvent-extracted whole fish—red hake, *Urophycis chuss* 145

EAR, DAVID, and IRWIN HAYDOCK. Laboratory rearing of the desert pupfish, *Cyprinodon macularius* .. 151

AYDOCK, IRWIN. Gonad maturation and hormone-induced spawning of the gulf croaker, *Bairdiella icistia* 157

CKEL, GUNTER R., and MARION Y. Y. YONG. Harmonic functions for sea-surface temperatures and salinities, Koko Head, Oahu, 1956-69, and sea-surface temperatures, Christmas Island, 1954-69 181

LLINEK, GISELA, and MAURICE E. STANSBY. Masking undesirable flavors in fish oils 215

OK, HARRY L., and M. ALICE MURPHY. Early developmental stages of the brown shrimp, *Penaeus aztecus* ves, reared in the laboratory 223

URY, BARBARA, JOHN SPINELLI, and DAVE WIEG. Protein autolysis rates at various pH's and temperatures in hake, *Merluccius productus*, and Pacific herring, *Clupea harengus pallasi*, and their effect on yield in the preparation of fish protein concentrate 241

Notes

ILIANI, DENNIS A. Equipment for holding and releasing penaeid shrimp during marking experiments 247

PP, ROBERT W., and FRANK H. HOFF. An adult bluefin tuna, *Thunnus thynnus*, from a Florida west coast urban waterway 251

LIBRARY
NATIONAL MARINE FISHERIES SERVICE
HONOLULU LABORATORY
P. O. BOX 3830
HONOLULU, HAWAII 96812

Wilbert McLeod Chapman

Milner Baily Schaefer

IN MEMORIAM

Wilbert McLeod Chapman and Milner Baily Schaefer

Fisheries science in particular and society in general suffered two tragic losses within the period of only a month with the deaths of W. M. Chapman on June 25, 1970, and M. B. Schaefer on July 26, 1970. It is indeed a strange and sad commentary that these two men whose careers were intimately entwined since college days should pass within such a short time of each other.

Death is never easy to accept; it is particularly hard to do so when it occurs at an untimely age. Both of these brilliant men, we would have hoped, would have been with us for years to come. Both were unique, each in his own way, and while the world adjusts to such events, each is in a very real sense irreplaceable.

I had the opportunity to work rather closely with both of them in California over most of the past two decades. Wib Chapman was a member of the California Marine Research Committee for many years, during most of which I served as that body's secretary. It was a challenge to try to capture the essence of his remarks. The breadth of his knowledge and the incisiveness of his thinking stimulated all of us to higher goals, and we who were close to him are better today for the good fortune of his friendship.

"Benny" Schaefer was equally brilliant. His expositions on the scientific method and population dynamics before the Inter-American Tropical Tuna Commission were models of translation into lay terms of highly complex mathematical theories applied to living resources. Again a personal note. A few years ago Benny was a consultant to the California Department of Fish and Game during the formation of that body's Fish and Wildlife Plan and we worked closely in developing the philosophy behind the sections concerned with living marine resources. His imprint is deeply ingrained in that document and in subsequent legislation, as well as in my thinking.

And, as Wib Chapman had a large input in that task, so did Benny into the deliberations of the Marine Research Committee. Meantime both worked diligently as members of the California Marine Advisory Committee on Marine and Coastal Affairs. While these men will rightfully be remembered for their major contributions to national and international affairs, their energy and interests were such that they encompassed an amazingly broad spectrum. Each of their contributions to the State of California is more than most men could accomplish in a lifetime devoted to that pursuit alone. One hears parallel stories throughout the scientific and fisheries communities.

★ ★ ★

Wilbert McLeod Chapman was born in Kalama, Washington, on March 31, 1910. He died in San Diego, California, on June 25, 1970, and is survived by his wife of 35 years, Mary Elizabeth, and five of their six children.

He did both his undergraduate and graduate work at the University of Washington, obtaining his Ph.D. (fisheries) in 1937. His publications, ranging from morphology and systematic ichthyology through fisheries economics and international law, number some 250. One of these, *Fishing in Troubled Waters,* is a book recounting his experiences as a fisheries development officer in the South Pacific during World War II. It is fascinating reading and makes one regret all the more that the other books he had in mind will never be forthcoming. He was particularly proud of his papers on systematics and morphology and always spoke fondly of that part of his career.

His honors were many: among them he was a Fellow of the Guggenheim Foundation and of the California Academy of Sciences, Man of the Year of the National Fisheries Institute in 1966,

and the recipient of the First Sea Grant College Award in 1968.

He began his professional career in 1933 with the International Fisheries (now Halibut) Commission. He was later employed by the Washington State Department of Fisheries, the U.S. Fish and Wildlife Service, and, in 1943, by the California Academy of Sciences where he was Curator of Fishes until 1947. It was during this period that he served in a civilian capacity in the South Pacific, his job being to develop subsistence fisheries at advanced island bases.

In 1947, Dr. Chapman became director of the School of Fisheries at the University of Washington. He left there in 1948 to become the first Special Assistant to the Under Secretary of State for Fish and Wildlife. In 1951 he became Director of Research for the American Tunaboat Association; a decade later he joined the Van Camp Sea Food Company as Director of the Division of Resources. When Van Camp was acquired by the Ralston Purina Company in 1968, he became Director, Marine Resources, of that firm, a position he held until his death.

★ ★ ★

Milner Baily Schaefer was born in Cheyenne, Wyoming, on December 14, 1912. He died in San Diego, California, on July 26, 1970. He is survived by his wife, Isabella, and three children.

Dr. Schaefer obtained his B.S. degree cum laude from the University of Washington in 1936 and his doctorate from the same institution in 1950. He worked for the Washington State Department of Fisheries from 1935 to 1938 and for the International Pacific Salmon Fisheries Commission from 1938 until 1942.

Following wartime duty with the Navy, he joined the U.S. Fish and Wildlife Service in 1946, serving first as a fishery research biologist in the South Pacific Fisheries Investigations at Stanford, and from 1948 to 1950 as Chief, Research & Development, Pacific Oceanic Fishery Investigations in Honolulu.

He became Director of Investigations of the Inter-American Tropical Tuna Commission in 1951, holding that post until he became Director of the Institute of Marine Resources and Professor of Oceanography, Scripps Institution of Oceanography, University of California, in 1962. He remained there until his death save for an 18-month period in 1967-69 during which he was Science Adviser to Secretary of the Interior Stewart Udall.

Among other honors, he was a fellow of the California Academy of Sciences and a member of the National Academy of Sciences. He wrote more than 100 scientific papers, particularly in the area of population dynamics and fisheries development and utilization. He served on a multitude of panels at the international, national and state levels. Despite his huge workload, he always found time to discuss individual problems with people both large and small, and to administer and develop first the Inter-American Tropical Tuna Commission and later the Institute of Marine Resources in an exemplary manner, setting standards for each that others will be hard-pressed to equal.

★ ★ ★

This recitation cannot give a measure of these men: their unflagging energy, their knowledge in fields far apart from fisheries, their ability as raconteurs, their good fellowship. Nor does it give a measure of their contributions to the nation and to the world, contributions that will help make it a better place in which to live for a long time to come.

Philip M. Roedel

KINDS AND ABUNDANCE OF FISH LARVAE IN THE EASTERN TROPICAL PACIFIC, BASED ON COLLECTIONS MADE ON EASTROPAC I

ELBERT H. AHLSTROM[1]

ABSTRACT

This paper deals with kinds and counts of fish larvae obtained in 482 oblique plankton hauls taken over an extensive area of the eastern tropical Pacific on EASTROPAC I, a four-vessel cooperative survey made during February-March 1967. On the basis of abundance of larvae, the dominant fish group in oceanic waters are the myctophid lanternfishes (47 %), gonostomatid lightfishes (23 %), hatchetfishes, Sternoptychidae (6 %), bathylagid smelts (5 %). Scombrid larvae ranked fifth, and exceeded 2 % of the count.

Two kinds of larvae were outstandingly abundant: larvae of the lanternfish *Diogenichthys laternatus* made up over 25 % of the total, while larvae of the gonostomatid genus *Vinciguerria* made up almost 20 %. More fish larvae were obtained per haul, on the average, in the eastern tropical Pacific than were obtained per haul in the intensively surveyed waters of the California Current region off California and Baja California.

EASTROPAC I was the first and most wide-ranging of a series of cooperative cruises made in the eastern tropical Pacific between February 1967 and April 1968. A vast expanse of the eastern tropical Pacific was surveyed on EASTROPAC I, extending from lat 20° N to 20° S, and from the American coasts offshore to long 126° W (Fig. 1). Four research vessels participated in EASTROPAC I: *Alaminos* operated by Texas A & M, occupied the inner pattern, while *Rockaway* operated by the U.S. Coast Guard, *David Starr Jordan* operated by the Bureau of Commercial Fisheries (now the National Marine Fisheries Service), and *Argo* operated by the Scripps Institution of Oceanography, occupied patterns successively seaward. The oceanographic, biological, and meteorological data collected on EASTROPAC cruises will be graphically presented in a series of EASTROPAC atlases, including generalized charts dealing with fish eggs and larvae.

The present paper is the result of a chain of events that began 2 decades ago, at the initiation of CalCOFI (California Cooperative Oceanic Fisheries Investigations) in which a large-scale sea program was set up to investigate the distribution and abundance of sardine spawning, and the factors underlying fluctuations in survival of the early life-history stages of sardines. The plankton collections not only contained eggs and larvae of sardine but those of most other pelagic fishes in the California Current region. A decision was made to attempt to identify and enumerate all fish larvae in the collections in order to obtain more precise information about the ecological associates of the sardine. At that time few fish larvae, other than those of the sardine and anchovy, could be identified.

Within a few years most kinds of fish larvae were identified to genus or species. Once the larvae were identified and enumerated, it became obvious that this was an exceptionally useful tool for evaluating fish resources. Most oceanic fishes have pelagic eggs and/or larvae that are distributed in or just below the photic zone, i.e. within the upper 150 to 200 m of depth. At no other time in their life histories are so many kinds of fishes associated together—deep-sea fishes (mesopelagic and bathypelagic) as well as epipelagic species—where they can be collected quantitatively with a single type of gear, a plankton net.

Once the larvae of the pelagic fish fauna of a region, such as those in the California Current region, are known, there is a large trans-

[1] National Marine Fisheries Service Fishery-Oceanography Center, La Jolla, Calif. 92037.

Manuscript received September 1970.

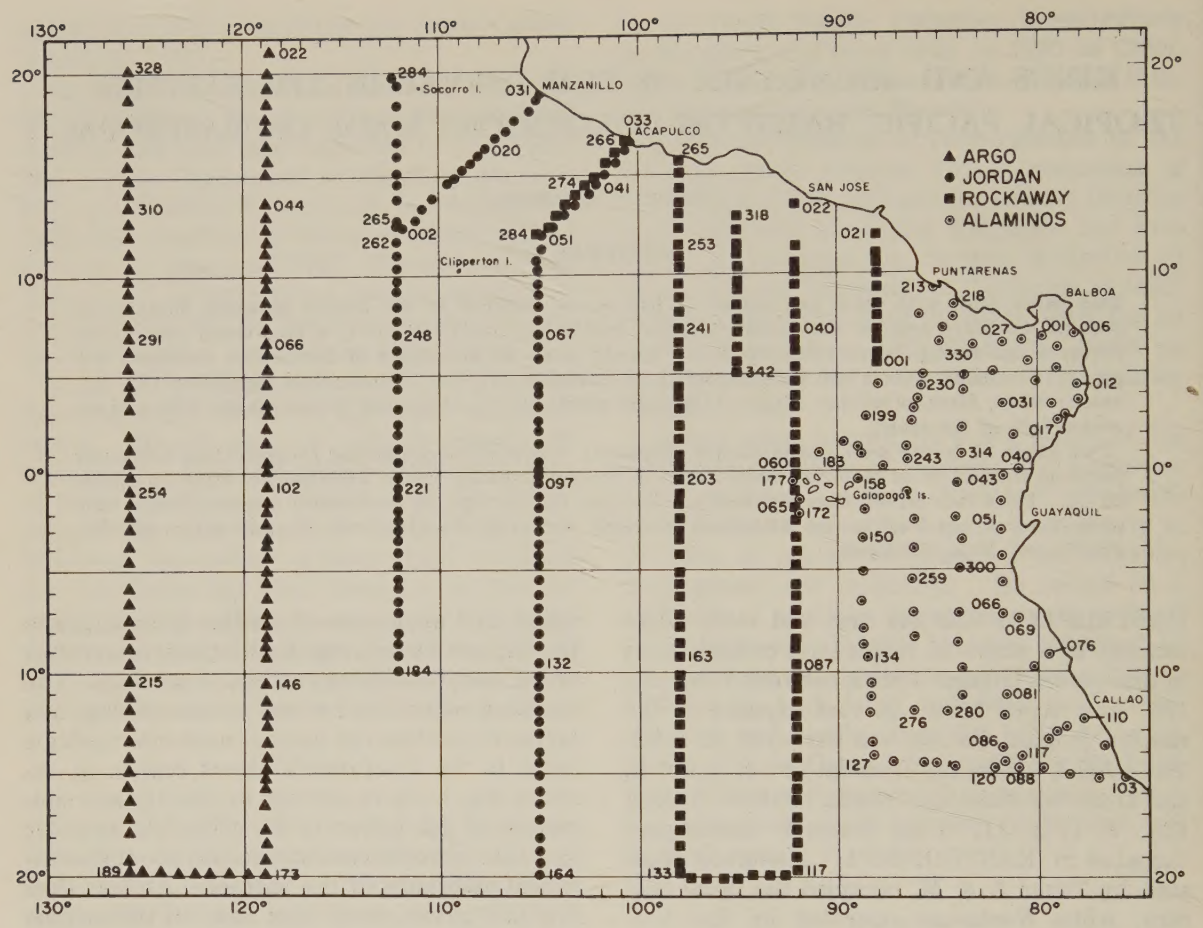


FIGURE 1.—Location of plankton stations occupied by four research vessels participating in EASTROPAC I. Symbols for vessels indicated in legend above. Samples collected from *Argo* are numbered as 11.000 series (as 11.022, 11.173), samples from *David Starr Jordan* as 12.000 series, *Rockaway* samples as 13.000 series and *Alaminos* samples as 14.000 series.

ference of the accumulated knowledge and skills for work in other areas, such as, in this instance, the eastern tropical Pacific. My study was undertaken to demonstrate the value of identifying all elements of the fish fauna of tropical regions, rather than restricting interest to scombrid larvae. Much information can be gained for little extra expense (a few percent of the cost of collecting the material at sea). Of equal consequence, identification of all kinds of fish larvae can be made more critically including scombrid larvae.

METHODS OF MAKING ZOOPLANKTON COLLECTIONS

Three nets, differing in size and in coarseness of mesh, were employed to collect zooplankton and micronekton on EASTROPAC cruises. In this paper I am concerned primarily with oblique hauls made with the net of intermediate size and mesh—a net, 1-m mouth diameter, constructed of 505 μ nylon (Nitex) cloth, with approximately a 5 to 1 ratio of effective straining surface (pore area) to mouth area. This net was paired in an assembly frame with a finer-

meshed net when hauled obliquely, but was used alone for taking surface hauls. The finer-meshed net was 0.5 m in diameter at the mouth, constructed of 333 μ Nitex cloth, with approximately an 8 to 1 ratio of effective straining surface to mouth area. The third net, used for collecting micronekton, had a 5-ft square mouth opening and was constructed of mesh measuring approximately 5.5 $\times$ 2.5 mm; this net could not be operated from the research vessel *Rockaway* on EASTROPAC I but was employed from the other three vessels.

Usually four zooplankton collections were made at each "biological" station: an oblique collection and a surface collection with the 1-m net, an oblique collection with the 0.5-m net, and an oblique collection with the micronekton net.

In taking oblique plankton hauls, the 1-m net was paired in an assembly frame with the 0.5 m net. The assembly of nets was fastened to the towing cable by a bridle about 5 m above a 100-lb weight. The assembly was lowered to depth by paying out 300 m of towing cable at the controlled rate of 50 m of wire per minute. The assembly remained at depth for 0.5 min and then was retrieved at a uniform rate of 20 m per min. Total towing time was about 21.5 min. Towing speed was ca. 2 knots. The depth reached by the net was estimated from the angle of stray (departure from the vertical) of the towing cable. We sought to maintain an angle of stray of 45°, which lowered the assembly to a depth of approximately 210 m. Our concern was to sample the upper 200-m stratum. The average depths of hauls taken by the four research vessels are summarized in Table 1. Over 80 % of the hauls made on EASTROPAC I were lowered to depths of 200 m or more, and nearly 95 % reached depths of 180 m or greater. However, two hauls were exceptionally shallow (71-90 m), and nine additional hauls were taken to depths of less than 150 m.

Usually four paired net-assembly hauls were taken per day, spaced at about 6-hr intervals. Although the four hauls were planned to be taken at about midnight, dawn, noon, and sunset, the timing of hauls was not coordinated between research vessels. The middle-of-the-night hauls were all taken before midnight (2201-2400) on *Rockaway*, for example, while on *Argo* most hauls were made after midnight (between 0001 and 0400 hr). The time of day of occupancy of stations (based on the midtime of each haul) is summarized by hourly intervals in Table 2. At least some hauls were taken during every hour of the day, although fewer than 10 (2-8) were obtained during six of the hourly intervals. Fewest hauls were obtained between 0901 and 1000 hr (2 hauls) and between 2101 and 2200 hr (4 hauls), whereas the largest number of hauls were taken between 2201 and 2300 hr (59 hauls) and between 1001 and 1100 hr (53 hauls). Hauls were made with equal frequency during the four periods of the day on *Argo*, *Jordan*, and *Rockaway;* most plankton hauls were taken near midnight or noon from *Alaminos*.

The numbering system for observations employed on EASTROPAC cruises made use of five digits divided into two groups, as 11.022, 12.002, etc. The outer digit preceding the period is the cruise number common to all vessels participating in a given EASTROPAC cruise; for EASTROPAC I, this number is 1. The other digit preceding the period is the identifying number given to each research vessel, with the lowest

TABLE 1.—Depth of paired oblique plankton hauls taken by the four research vessels on EASTROPAC I. (Net lowered by paying out 300 m of towing cable)

Average depth of haul	Number of hauls taken to each depth interval from				
	Argo	*David Starr Jordan*	*Rockaway*	*Alaminos*	All vessels
M					
70.1- 80.0	--	--	--	1	1
80.1- 90.0	--	--	--	1	1
90.1-100.0	--	--	--	--	--
100.1-110.0	--	--	--	1	1
110.1-120.0	--	--	--	--	--
120.1-130.0	2	--	--	3	5
130.1-140.0	1	--	--	1	2
140.1-150.0	--	1	--	--	1
150.1-160.0	--	--	1	2	3
160.1-170.0	2	--	2	2	6
170.1-180.0	2	2	2	1	7
180.1-190.0	15	5	4	5	29
190.1-200.0	21	10	11	10	52
200.1-210.0	41	59	58	30	188
210.1-220.0	26	44	57	41	168
220.1-230.0	9	--	3	5	17
230.1-240.0	--	--	1	--	1
Total	119	121	139	103	482

TABLE 2.—Hour of day that paired oblique plankton hauls were taken from the four research vessels participating in EASTROPAC I. (Midtime of haul used.)

Hours of day	Number of hauls taken during each hour of the day from				
	Argo	*David Starr Jordan*	*Rockaway*	*Alaminos*	All vessels
0001-0100	7	10	0	3	20
0101-0200	8	7	0	2	17
0201-0300	5	2	0	0	7
0301-0400	9	0	7	0	16
0401-0500	1	1	17	1	20
0501-0600	2	9	10	3	24
0601-0700	7	10	1	1	19
0701-0800	13	10	0	0	23
0801-0900	7	0	0	0	7
0901-1000	0	0	0	2	2
1001-1100	1	0	26	26	53
1101-1200	1	5	5	10	21
1201-1300	7	22	3	1	33
1301-1400	12	3	1	4	20
1401-1500	8	0	0	0	8
1501-1600	1	1	12	1	15
1601-1700	0	0	10	3	13
1701-1800	8	6	12	6	32
1801-1900	7	19	1	0	27
1901-2000	10	1	0	0	11
2001-2100	3	3	0	0	6
2101-2200	0	1	0	3	4
2201-2300	2	2	23	32	59
2301-2400	0	9	11	5	25
Total	119	121	139	103	482

number given to the offshore vessel. The three digits following the period are numbers given to observations made from each vessel during a cruise, numbered sequentially. Not all "stations" included oblique plankton hauls; hence there are gaps in numbers applied to plankton collections.

The locations of plankton stations occupied by the four research vessels participating in EASTROPAC I are shown in Figure 1. Samples collected from the *Argo* are designated as the 11.000 series, samples from the *David Starr Jordan* as 12.000 series, *Rockaway* samples as 13.000 series and *Alaminos* samples as 14.000 series. In tables to follow, the series of samples taken by each vessel is designated by the above identifying series numbers. The aggregate of stations occupied by each vessel is referred to in text discussions as its pattern.

PROCESSING SAMPLES ASHORE

As noted above, only samples from 1-m oblique net hauls were sorted routinely for fish eggs and larvae. As a rule the entire sample was sorted; in fact only six collections out of 482 were aliquoted — four collections were split into 50 % aliquots, two collections into 25 % aliquots.

The author made all identifications and counts of larvae from EASTROPAC I collections. Actual counts of larvae rather than standardized values (see below) are used in tabulation throughout this paper, except one (Table 7). There are several reasons why I chose to do this. As indicated previously, all hauls were made in a roughly comparable fashion. In many studies the investigator is interested in the presence or absence of the larvae of a given species or assemblage of species as such relate to water masses, community composition, time of day, etc. Such information is most readily obtained from records of actual counts. Some statistical tests require the use of original counts rather than standardized data. For persons interested in deriving standardized counts comparable with those employed for CalCOFI data (Ahlstrom, 1953), standard haul factors for the 482 oblique hauls taken with the 1-m net on EASTROPAC I are given in Appendix Table 7.

Two major considerations in the quantitative sampling of fish larvae for resources evaluation are (1) how well has their depth range been covered and (2) how effectively have the larvae been sampled within this layer?

We do not have direct answers to either of these questions from EASTROPAC cruises. No studies were made on depth distributions of fish eggs and larvae in the EASTROPAC area. As will appear, fewer fish larvae were obtained during daylight hours than in night hauls; however, we lack information on how completely larvae were sampled in night hauls.

DEPTH DISTRIBUTION OF FISH LARVAE

Although collecting methods used on EASTROPAC did not permit a study of depth distribution of fish larvae, such information for the California Current region off California and Baja California and in a less detailed way for the NORPAC Expedition of 1955 are available (Ahlstrom, 1959).

In the California Current region, most fish eggs and larvae were distributed within the up-

per mixed layer or in the upper portion of the thermocline, between the surface and approximately 125 m. Of the 15 most common kinds of fish larvae taken in vertical distribution series, 12 were so distributed (ibid., p. 134). Two of the kinds that occurred most commonly below the thermocline were bathylagid smelts, closely related to the two common bathylagid smelts taken on EASTROPAC I.

On the NORPAC Expedition of August 1955, two depth strata were sampled at most stations; a closing net, fastened to the towing cable 200 m below a standard open plankton net, sampled the level between 262 and 131 m on the average, while the upper net sampled from the surface to approximately 131 m deep. Only about one-ninth as many larvae were taken in the closing net hauls as in the upper net hauls; fully half of these were larvae of hatchetfish, family Sternoptychidae, largely absent from upper net hauls. The two most abundant kinds of fish larvae taken on EASTROPAC I were those of the myctophid lanternfish, *Diogenichthys laternatus*, and of the gonostomatid lightfish, *Vinciguerria* spp. In NORPAC collections, only 3 % of the larvae of *D. laternatus* were taken in the closing net hauls and only 2 % of the *Vinciguerria* larvae. Among the kinds of larvae common to both the NORPAC and EASTROPAC surveys that occurred in significant numbers in the deeper NORPAC collections were those of *Chauliodus* (72 % taken in closing net hauls), *Protomyctophum* (48 %) and *Idiacanthus* (32 %).

Inasmuch as the vertical distribution studies in the California Current region had pointed up the importance of the thermocline in the depth distribution of larvae, the pattern of thermocline depth was analyzed for EASTROPAC I (Table 3).

Thermocline depth was invariably shallow in the inner pattern occupied by *Alaminos* (data not included in Table 3); the greatest depth recorded was only 40 m, and the majority of observations were at depths shallower than 20 m. Along the six station lines covered in Table 3, thermocline depths were shallowest near the equator, and usually were deepest at the northern (20-15° N) and southern (15-20° S) ends of the lines. The thermocline also deepened offshore; approximately three-fourths of the records of thermocline depths of 50 m or greater were from the two outer lines, occupied by *Argo*.

Most oblique plankton hauls taken on EASTROPAC I sampled to depths of 200 m or more (Table 2), hence sampled considerably deeper than the thermocline in all parts of the EASTROPAC area.

EFFECTIVENESS OF SAMPLING FISH LARVAE IN DAYLIGHT HAULS AS COMPARED WITH NIGHT HAULS

Fewer fish larvae were obtained in hauls made during daylight hours than at night (Table 4). Original (unstandardized) counts of larvae averaged 2.76 times as many in night hauls as in day hauls, 285 larvae per occupancy as compared with 103 larvae. Hauls made within 1 hr of sunrise or sunset contained intermediate numbers of larvae, averaging 217 larvae per occupancy.

TABLE 3.—Summary of records of thermocline depths along six station lines occupied by the research vessels *Rockaway*, *David Starr Jordan*, and *Argo* on EASTROPAC I.

Station line along longitude	Range in depth of thermocline *(m)* at latitudes								All latitudes
	20-15° N	15-10° N	10-5° N	5° N-0°	0-5° S	5-10° S	10-15° S	15-20° S	
92° W	--	0-15	7-14	5-29	0-16	15-40	24-45	30-54	0-54
98°	16-30	13-68	23-44	5-13	2-27	13-32	20-48	40-60	2-68
105°	--	37-50	27-44	0-20	0-28	23-45	26-55	54-66	0-66
112°	8-42	41-79	32-58	0-37	2-22	33-52	--	--	0-79
119°	36-67	44-90	42-55	0-85	0-65	34-76	50-73	30-71	0-90
126°	52-116	45-79	35-49	0-42	0-60	40-71	43-71	43-70	0-116
% obs. with T. D. shallower than 10.1 m	17 %	8 %	7 %	46 %	43 %	0	0	0	20 %
% obs. with T. D. deeper than 49.9 m	56 %	46 %	9 %	11 %	9 %	25 %	35 %	63 %	26 %

TABLE 4.—Occurrence (positive hauls) and abundance (original counts) of fish larvae in day hauls as compared with night hauls and with hauls taken within 1 hr of sunrise or sunset, summarized by family and vessel pattern.

Vessel pattern and family	Day hauls			Night hauls				Hauls within ± 1 hr of sunrise or sunset			Total hauls		
	Number positive hauls	Total larvae	Average number per occupancy (D)	Number positive hauls	Total larvae	Average number per occupancy (N)	N/D	Number positive hauls	Total larvae	Average number per occupancy	Number positive hauls	Total larvae	Average number per occupancy
11.000 series													
Argo	(44)[1]			(42)				(33)			(119)		
Myctophidae	43	1,129	25.7	42	4,412	105.0	4.09	33	1,452	44.0	118	6,993	58.8
Gonostomatidae	44	727	16.5	42	2,619	62.4	3.78	32	1,317	39.9	118	4,663	39.2
Sternoptychidae	36	327	7.4	33	343	8.2	1.10	21	253	7.7	90	923	7.8
Bathylagidae	15	96	2.2	21	103	2.4	1.12	13	85	2.6	49	284	2.4
Melamphaidae	26	65	1.5	23	65	1.6	1.05	17	35	1.1	66	165	1.4
Scombridae	5	21	0.5	13	29	0.7	1.44	8	187	5.7	26	237	2.0
All others	42	687	15.6	42	1,012	24.1	1.54	32	555	16.8	116	2,254	18.9
Total	44	3,052	69.4	42	8,583	204.4	2.95	33	3,884	117.8	119	15,519	130.5
12.000 series													
Jordan	(34)			(37)				(50)			(121)		
Myctophidae	34	1,257	37.0	37	5,389	145.6	3.94	50	4,628	92.6	121	11,274	93.2
Gonostomatidae	32	451	13.3	37	2,417	65.3	4.91	49	1,914	38.1	118	4,782	39.5
Sternoptychidae	22	452	13.3	21	503	13.6	1.02	31	757	15.1	74	1,712	14.1
Bathylagidae	20	105	3.1	20	168	4.5	1.45	33	223	4.5	73	496	4.1
Melamphaidae	21	43	1.3	28	58	1.6	1.25	28	70	1.4	77	171	1.4
Scombridae	9	80	2.4	16	129	3.5	1.49	19	133	2.7	44	342	2.8
All others	34	766	22.5	37	2,009	56.8	2.52	49	1,244	24.9	120	4,109	34.0
Total	34	3,154	92.9	37	10,763	290.9	3.13	50	8,969	179.5	121	22,886	189.1
13.000 series													
Rockaway	(65)			(59)				(15)			(139)		
Myctophidae	65	3,761	57.9	58	8,557	145.0	2.50	14	2,911	194.1	137	15,229	109.6
Gonostomatidae	62	1,138	17.5	59	5,608	95.0	5.43	14	1,383	92.2	135	8,129	58.5
Sternoptychidae	47	798	12.3	45	829	14.1	1.14	14	534	35.6	106	2,161	15.5
Bathylagidae	43	475	7.3	37	411	7.0	0.95	13	189	12.6	93	1,075	7.7
Melamphaidae	42	130	2.0	43	132	2.2	1.12	11	59	3.9	96	321	2.3
Scombridae	30	131	2.0	29	435	7.4	3.65	10	39	2.6	69	605	4.4
All others	62	1,009	15.5	59	2,422	41.1	2.65	15	429	28.6	136	3,860	27.8
Total	65	7,442	114.5	59	18,394	311.8	2.72	15	5,544	369.6	139	31,380	225.8
14.000 series													
Alaminos	(50)			(46)				(7)			(103)		
Myctophidae	46	2,523	50.5	43	6,640	144.3	2.86	7	2,254	322.0	96	11,417	110.8
Gonostomatidae	41	874	17.5	41	2,550	55.4	3.17	6	1,048	149.7	88	4,472	43.4
Sternoptychidae	31	312	6.2	31	565	12.3	1.97	5	14	2.0	67	891	8.7
Bathylagidae	40	1,015	20.3	43	1,809	39.3	1.94	6	201	28.7	89	3,025	29.4
Melamphaidae	28	69	1.4	26	104	2.3	1.64	5	27	3.9	59	200	1.9
Scombridae	16	65	1.3	25	448	9.7	7.49	5	222	31.7	46	735	7.2
All others	45	1,406	28.1	45	2,557	55.6	1.98	6	621	88.7	96	4,584	44.5
Total	46	6,264	125.3	46	14,673	318.9	2.55	7	4,387	626.7	99	25,324	245.9
Complete EASTROPAC I	(193)			(184)				(105)			(482)		
Myctophidae	188	8,670	44.9	180	24,998	135.9	3.03	104	11,245	107.1	472	44,913	93.2
Gonostomatidae	179	3,190	16.5	179	13,194	71.7	4.35	101	5,662	53.9	459	22,046	45.7
Sternoptychidae	136	1,889	9.8	140	2,240	12.2	1.24	71	1,558	14.8	337	5,687	11.8
Bathylagidae	118	1,691	8.8	121	2,491	13.5	1.54	65	698	6.7	304	4,880	10.1
Melamphaidae	117	307	1.6	120	359	1.9	1.23	61	191	1.8	298	857	1.8
Scombridae	60	297	1.5	83	1,041	5.7	3.68	42	581	5.5	185	1,919	4.0
All others	183	3,868	20.0	183	8,090	44.0	2.20	102	2,849	27.2	468	14,807	30.7
Total	189	19,912	103.1	184	52,413	284.9	2.76	105	22,784	217.0	478	95,109	197.3

[1] Total number of hauls.

Larvae of some families of fishes were sampled almost as well in day hauls as in night hauls —including Sternoptychidae, Bathylagidae, and Melamphaidae. In contrast, less than one-fourth as many gonostomatid larvae and one-third as many myctophid larvae were taken in day hauls, on the average, as in night hauls. Catches of scombrid larvae were more variable with regard to time of sampling—the night-day ratio in the outer half of the EASTROPAC area was only about 1.5 to 1, whereas the ratio jumped to about 7.5 to 1 in the inner pattern occupied by *Alaminos*. Larvae collected about in equal amounts in day and night hauls were those known to occur principally below the thermocline.

Despite the lower abundance of larvae in day hauls as compared with night hauls, the percentage of hauls containing larvae of most families was only slightly lower (Table 5). The most marked day/night difference in frequency of occurrence was for scombrid larvae, these were taken in 45 % of night hauls, but in only 31 % of day hauls. In the discussions that follow I make use of all collection data, irrespective of time of collection.

TABLE 5.—Percentage of hauls containing larvae of the more abundant fish families on EASTROPAC I, grouped by day, night and dawn or sunset.

Family	Day hauls	Night hauls	Dawn or sunset hauls (± 1 hr)	All hauls
	%	%	%	%
Myctophidae	97.4	97.8	99.0	97.9
Gonostomatidae	92.7	97.3	95.2	95.0
Sternoptychidae	70.5	76.1	67.6	69.9
Bathylagidae	61.1	65.2	61.9	62.9
Melamphaidae	60.6	65.2	58.1	61.8
Scombridae	31.1	45.1	40.0	38.4
All others	94.8	99.5	97.1	97.1
Total	97.9	100.0	100.0	99.2

NUMBERS OF FISH LARVAE OBTAINED ON EASTROPAC I

Fish larvae were obtained in 478 of 482 oblique plankton tows made with the 1-m plankton net on EASTROPAC I. The number of larvae per collection ranged from 0 to 2,197, averaging 197 larvae (actual counts).

Differences in abundance of larvae with latitude are summarized for the four series in Table 6. Fish larvae were obtained in largest numbers, on the average, in an equatorial band extending from about lat 10° N to 5° S. The least productive waters for fish larvae were in the central water mass of the South Pacific, especially between lat 15° and 20° S.

Abundance of fish larvae also decreased offshore, averaging only 130 larvae per haul in the outer pattern, occupied by *Argo*, as compared with 246 larvae per haul in the inner pattern, occupied by *Alaminos*.

Tropical waters and oceanic waters are usually considered to be relatively unproductive, compared with temperate coastal regions such as the California Current region (Ryther, 1969). Hence, it is surprising to find that the average number of fish larvae obtained per haul on EASTROPAC I was larger than either on the CalCOFI cruises from the California Current region (Ahlstrom, 1969) or on NORPAC (un-

TABLE 6.—Total catches of fish larvae (actual counts) taken by the four research vessels on EASTROPAC I, summarized by latitude.

Latitude	*Argo* 11.000 Series		*David Starr Jordan* 12.000 Series		*Rockaway* 13.000 Series		*Alaminos* 14.000 Series		Total EASTROPAC I		
	No. hauls	No. larvae	No. hauls	No. larvae	No. hauls	No. larvae	No. hauls	No. larvae	No. hauls	No. larvae	Average no. larvae per haul
20° N-15° N	16	1,070	20	4,128	5	462	--	--	41	5,660	138.0
15° N-10° N	14	1,372	23	3,130	26	5,508	--	--	63	10,010	158.0
10° N- 5° N	14	2,516	14	3,344	29	10,104	15	5,167	72	21,131	293.5
5° N- 0°	14	4,797	15	4,403	14	4,331	27	11,329	70	24,860	355.1
0° - 5° S	14	2,089	18	5,454	14	4,350	17	5,042	63	16,935	268.8
5° S-10° S	13	1,370	15	1,051	14	2,360	16	2,113	58	6,894	118.9
10° S-15° S	14	1,512	8	863	15	2,337	28	1,673	65	6,385	98.2
15° S-20° S	20	793	8	513	22	1,928	--	--	50	3,234	64.7
Total	119	15,519	121	22,886	139	31,380	103	25,324	482	95,109	197.3

published data). Standard haul totals of larvae are used in this comparison (Table 7) not original counts. CalCOFI cruises repeatedly surveyed a coastal area extending 200 to 300 miles offshore between San Francisco, California, and Magdalena Bay, Baja California. NORPAC was the first comprehensive survey of the North Pacific, made in August-September 1955; the area surveyed by four CalCOFI vessels participating in NORPAC was between lat 20° and 45° N and offshore to long 150° W.

TABLE 7.—Comparison of the average number of fish larvae obtained per haul (standard haul values) EASTROPAC I, NORPAC, and CalCOFI cruises.

Cruises	Year	Number hauls	Average depth of hauls	Total number of fish larvae[1]	Average number larvae/haul
EASTROPAC I	1967	482	ca. 200 m	274,131	569
NORPAC	1955	196	ca. 260 m	27,000	[2]138
CalCOFI cruises	1956	1,407	ca. 140 m	408,140	290
	1957	1,493	ca. 140 m	493,550	331
	1958	1,852	ca. 140 m	456,020	246
	1959	2,182	ca. 140 m	470,450	216
	1960	1,826	ca. 140 m	504,980	277

[1] Standard haul totals.
[2] Data from two net hauls combined: an average of 124 larvae per haul were taken in upper net hauls (0 to 130 m) and an average of 14 larvae per haul in closing net hauls, sampling between ca. 260 and 130 m.

EASTROPAC hauls sampled a somewhat deeper stratum than hauls made on CalCOFI cruises, ca. 200 m as compared to ca. 140 m. As indicated previously, information is available for the majority of NORPAC stations on the relative abundance of fish larvae in the level between ca. 130 and 260 m (closing net hauls) as compared with the level above, 0 to 130 m. Only about one-ninth as many larvae were taken in the deeper hauls.

The difference between catches of larvae on EASTROPAC I and NORPAC are particularly marked—four times as many larvae were taken per haul, on the average, on EASTROPAC I as on NORPAC (both nets combined). For comparison with shallower CalCOFI hauls, I am assuming that 10 % of the EASTROPAC larvae were obtained in the level between ca. 140 and 200 m. The adjusted value for EASTROPAC larvae, 512 larvae per haul, on the average, is 1.55 times as large as the highest CalCOFI value listed (331 larvae per haul in 1957) and 2.35 times as large as the lowest value (216 larvae per haul in 1959).

The majority of EASTROPAC larvae were those of fishes which never attain a large size as adults—myctophids, gonostomatids, sternoptychids, etc.—hence numbers of larvae, per se, cannot be considered reliable indices of biomass. The familial composition of larvae was not dissimilar on NORPAC and EASTROPAC, however; hence this comparison of relative abundance of larvae is more relevant, as regards biomass, than the comparison with CalCOFI fauna.

KINDS OF FISH LARVAE OBTAINED ON EASTROPAC I

The kinds of larvae obtained on EASTROPAC I are summarized by family and vessel pattern in Table 8, the principal summary table in this paper. Larvae of more than 50 families are listed, but larvae of 10 families contributed 90 % of the total. The myctophids were the dominant group with 47.2 % of the larvae occurring in nearly 98 % of the collections. Gonostomatid larvae were about half as numerous, contributing 23.2 % of the larvae while occurring in 95 % of the collections. Hatchetfish larvae (Sternoptychidae) ranked third in abundance with 6 % of the larvae taken in 70 % of the hauls. Bathylagid larvae also exceeded 5 % of the total and occurred in 63 % of the collections. Scombrid larvae ranked fifth and exceeded 2 % of the count, followed by Bregmacerotidae, 1.9 %, Paralepididae, 1.7 %, Idiacanthidae, 1.0 %, Nomeidae, 1.0 %, and Melamphaidae, 0.9 %. About one-third of the remaining larvae were too poorly preserved (disintegrated) to identity.

On the basis of larval abundance, the dominant orders of fishes in oceanic waters are the Myctophiformes and Salmoniformes, making up between 85 and 88 %; the latter value assumes a proportionate representation of larvae of these groups in the "disintegrated" category, i.e., larvae too damaged or disintegrated to identify with certainty. Despite the dominance of fishes of the above two orders, a number of other groups of fishes are represented in the oceanic pelagic fish fauna. The berycoid fishes are rep-

TABLE 8.—Occurrences and counts of fish larvae taken in oblique 1.0-m plankton hauls on EASTROPAC I, summarized by family or larger grouping and by research vessel.

Family or larger grouping	Basic station data contained in Appendix Table no.		*Argo* 11.000 series		*David Starr Jordan* 12.000 series		*Rockaway* 13.000 series		*Alaminos* 14.000 series		Total EASTROPAC I	
	By family or larger grouping	By genus or species	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae
[1]*1 Clupeidae	4		0	0	1	1	3	5	6	75	10	81
*2 Engraulidae	4		0	0	1	2	2	20	7	183	10	205
*3 Argentinidae		3	8	12	22	54	11	19	2	2	43	87
*4 Bathylagidae	1	3	49	284	73	496	93	1,075	89	3,025	304	4,880
*5 Gonostomatidae	1	3	118	4,663	118	4,782	135	8,129	88	4,472	459	22,046
*6 Sternoptychidae	1		90	923	74	1,712	106	2,161	67	891	337	5,687
*7 Astronesthidae	1		5	6	4	4	1	1	2	2	12	13
*8 Chauliodontidae	1		19	37	23	75	20	30	18	23	80	165
*9 Idiacanthidae	1		42	147	46	395	46	311	33	107	167	960
*10 Other Stomiatoidei	1	3	41	77	58	155	60	170	44	100	203	502
*11 Synodontidae	4		0	0	1	1	2	2	7	38	10	41
*12 Chlorophthalmidae			0	0	0	0	1	4	0	0	1	4
*13 Myctophidae	1	2	118	6,993	121	11,274	137	15,229	96	11,417	472	44,913
*14 Paralepididae	1	3	67	242	97	558	82	523	44	325	290	1,648
*15 Evermannellidae	3		14	20	4	6	9	12	0	0	27	38
*16 Scopelarchidae	1		35	64	46	104	39	120	22	41	142	329
*17 Scopelosauridae		3	2	2	3	3	1	1	3	10	9	16
18 Other Myctophiformes			7	8	2	2	1	2	2	2	12	14
19 Giganturidae			1	1	0	0	0	0	0	0	1	1
*20 Eel leptocephali	1		19	46	15	22	23	38	30	73	87	179
*21 Melamphaidae	1		66	165	77	171	96	321	59	200	298	857
22 Holocentridae			0	0	0	0	3	4	1	1	4	5
*23 Bregmacerotidae	1		62	291	56	825	56	435	21	254	195	1,805
24 Macrouridae			0	0	0	0	1	1	2	2	3	3
25 Scomberesocidae			0	0	0	0	1	1	0	0	1	1
*26 Exocoetidae	1	3	9	15	26	65	28	75	15	34	78	189
27 Trachypteridae	3		13	13	14	16	8	8	10	10	45	47
*28 Gempylidae-Trichiuridae	1	5	19	26	18	28	31	103	35	74	103	231
*29 Scombridae	1	3	26	237	44	342	69	605	46	735	185	1,919
*30 Istiophoridae			2	2	0	0	0	0	0	0	2	2
31 Ammodytidae			0	0	0	0	3	4	4	4	7	8
*32 Apogonidae		3	35	115	15	64	9	23	2	2	61	204
33 Balistidae			0	0	0	0	1	1	1	2	2	3
34 Bramidae	1		28	46	9	10	13	14	9	11	59	81
35 Callionymidae			0	0	0	0	0	0	8	12	8	12
*36 Carangidae	4	3	1	1	7	12	4	84	19	86	31	183
37 Carapidae			0	0	0	0	1	1	2	2	3	3
38 Champsodontidae			5	6	0	0	0	0	0	0	5	6
39 Chiasmodontidae	1		15	43	11	28	20	40	18	30	64	141
*40 Coryphaenidae		3	24	29	23	36	19	25	20	28	86	118
41 Gobiidae	4		0	0	7	17	23	262	30	251	60	530
42 Labridae	4		0	0	3	4	6	8	19	28	28	40
43 Mugilidae			0	0	0	0	0	0	5	9	5	9
*44 Nomeidae	1		39	178	52	346	51	291	36	146	178	961
45 Ophidiidae			1	1	1	1	0	0	4	18	6	20
46 Polynemidae			0	0	0	0	2	3	3	8	5	11
47 Sciaenidae			0	0	1	6	2	4	1	2	4	12
48 Scorpaenidae	4		1	1	5	8	15	41	27	113	48	163
49 Serranidae	4		0	0	3	15	3	53	20	184	26	252
50 Sphyraenidae			0	0	0	0	2	2	1	1	3	3
*51 Tetragonuridae		3	4	5	0	0	2	2	0	0	6	7
52 Triglidae			0	0	0	0	2	4	4	19	6	23
53 Uranoscopidae			0	0	0	0	0	0	1	1	1	1
*54 Bothidae		6	0	0	3	14	24	106	29	79	56	199
*55 Cynoglossidae		6	0	0	5	17	21	102	37	185	63	304
56 Lophiiformes	3		31	48	34	55	37	69	38	95	140	267
57 Other, including unidentified	1		69	257	56	323	54	436	57	523	236	1,539
58 Disintegrated larvae	1		89	515	97	837	90	400	73	1,389	348	3,141
Total			119	15,519	121	22,886	139	31,380	[2]99	25,324	[2]478	95,109

[1] Categories preceded by an asterisk are discussed in the text.
[2] No fish larvae were taken in four hauls of 14.000 series, hence total number of oblique 1.0-m collections was 482.

resented by Melamphaidae, a family of fishes that is almost as ubiquitous as the myctophids or gonostomatids. Fishes of the gadoid family, Bregmacerotidae, also are widely distributed in the warmer waters of all oceans. Among the ubiquitous epipelagics are the flyingfishes, Exocoetidae.

Only a moderate number of perciform fishes are widely distributed in offshore, oceanic waters. Among the more important are fishes of the families Scombridae, Gempylidae, Trichiuridae, Istiophoridae, Coryphaenidae, Bramidae, Nomeidae, Apogonidae, Chiasmodontidae, and Tetragonuridae.

Larvae of some demersal fishes have a much wider offshore distribution than one would associate with the known distribution of adults. Included in this group are larvae of bothid and cynoglossid flatfishes, and larvae of Scorpaenidae, Gobiidae, and Labridae.

Another widely distributed group in oceanic waters are the bizarre ceratioid fishes. The rotund larvae of these fishes were taken in about 30 % of the EASTROPAC collections, always in small numbers.

The basic data on the kinds and numbers of fish larvae obtained in the 482 EASTROPAC I collections are contained in six appendix tables, whose contents are summarized below, and keyed to Table 8 and to other tables in this report.

Appendix Table 1.—Counts of fish larvae, tabulated by family, for all stations occupied on EASTROPAC I. This table contains 22 categories, mostly families, but for completeness, a category is included for "other identified larvae," one for "unidentified larvae" and one for "disintegrated larvae" (i.e., larvae too damaged or disintegrated to identify with any certainty).

Appendix Table 2.—Myctophid larvae, tabulated by genus or species, for all stations occupied on EASTROPAC I. Myctophid larvae are tabulated by species for 12 kinds, and by genus for 8 kinds. Also included are categories for unidentified myctophids, and total myctophids. A summary of this appendix table is contained in Table 15.

Appendix Table 3.—Counts of selected categories of fish larvae by station. Table contains 23 categories including 10 species, 10 genera, 2 families, and 1 suborder; 9 of these were included in the category "other identified larvae" in Appendix Table 1.

Appendix Table 4.—Summary of occurrences and numbers of larvae of eight families limited in distribution to a broad coastal band or around offshore islands. Only positive stations are included. These eight families also were included in the category " other identified larvae" in Appendix Table 1.

Appendix Table 5.—Numbers and kinds of larvae of Gempylidae-Trichiuridae obtained in EASTROPAC I collections. Only positive stations are included. A summary of this appendix table is given in Table 19.

Appendix Table 6.—Numbers and kinds of flatfish (Pleuronectiformes) larvae obtained in EASTROPAC I collections. Only positive hauls are included. A summary of this appendix table is given in Table 22.

Appendix Table 7.—Standardized haul factors for the 482 oblique 1-m net hauls taken on EASTROPAC I. These factors adjust original counts of larvae to the comparable standard of numbers of larvae in 10 m^3 of water strained per meter of depth fished.

I will not attempt to comment on all 58 categories (family or larger grouping) summarized in Table 8, but will limit my discussion to 31 of these. In order to tie the text discussion closely to this table, I retain the numbers for categories as given in Table 8; those discussed in the text are preceded by an asterisk in this table.

COMMENTS ON LARVAE OF THE MAJOR FISH FAMILIES COLLECTED ON EASTROPAC I

1. CLUPEIDAE
(10 occurrences, 81 larvae)

Three species of clupeid larvae were taken in EASTROPAC I collections—*Opisthonema* sp.

(5 occurrences, 12 larvae), *Etrumeus acuminatus* Gilbert (2 occurrences, 6 larvae), and *Sardinops sagax* (Jenyns) (3 occurrences, 63 larvae). The latter two species were collected in the vicinity of the Galápagos Islands.

2. ENGRAULIDAE
(10 occurrences, 205 larvae)

The majority of the engraulids (5 occurrences, 174 specimens) were those of the Peruvian anchovy, *Engraulis ringens* Jenyns, collected at coastal stations between lat 6° and 13.5° S. Although larvae from only a few surface hauls have been sorted as yet, one haul was outstanding: the surface tow taken at station 14.069 contained 10,466 larvae and transforming specimens of Peruvian anchovy, *E. ringens*. Specimens ranged in size from 3.5 to 37.5 mm; most were between 4.0 and 7.5 mm in length but even transforming specimens, 20.0 to 37.5 mm long, were rather common (83 individuals). In the oblique 1-m haul at this station, 97 anchovy larvae were obtained.

3. ARGENTINIDAE
(43 occurrences, 87 larvae)

Three kinds of argentinid larvae were obtained: *Argentina* sp. (1 specimen), *Nansenia* sp. A (84 larvae), and *Nansenia* sp. B. (2 larvae). The specific identities of the two kinds of *Nansenia* larvae are still uncertain. On EASTROPAC I, *Nansenia* sp. A was taken most commonly in an equatorial band between lat 5° N and 5° S (Fig. 2). Larvae of *Nansenia* sp. A also occur in the southern portion of the area surveyed on cruises of CalCOFI, particularly to the south of Point San Eugenio, Baja California. A *Nansenia* larva with markedly different pigmentation pattern was obtained at station 11.154 in the central water mass of the South Pacific. A similarly pigmented *Nansenia* larva was obtained on NORPAC from the central water mass of the North Pacific.

4. BATHYLAGIDAE
(304 occurrences, 4,880 larvae)

Although two kinds of *Bathylagus* larvae were obtained, one species was taken in only two contiguous southern stations, 12.142 and 12.144. The eyes of the latter were carried on short stalks. The distribution of larvae of the commonly occurring species, *B. nigrigenys* Parr (296 occurrences, 2,987 larvae), was almost identical with that of the myctophid, *Diogenichthys laternatus* (Garman) (Fig. 3). The larvae of neither species occurred in the central South Pacific water mass; on the four outer lines, surveyed by *Argo* and *Jordan*, the occurrences of *B. nigrigenys* larvae ended at about lat 5° S. In the portion of the EASTROPAC area in which larvae of this species were distributed, they occurred in three-fourths of the stations occupied.

In the innermost pattern occupied by *Alaminos*, larvae of *Leuroglossus stilbius urotranus* (Bussing, 1965) were common (37 occurrences, 1,890 larvae). All but four specimens were obtained between lat 10° N and 10° S, and most within 300 miles of the coast (Fig. 2).

5. GONOSTOMATIDAE
(459 occurrences, 22,046 larvae)

Areal occurrence and relative abundance of gonostomatid larvae on EASTROPAC I are summarized in Table 9. They were obtained in 95 % of the hauls and made up approximately 23.2 % of the larvae.

As noted earlier, gonostomatid larvae were markedly more abundant in night hauls than in day hauls: 4.35 times as many, on the average. In contrast, larvae of the closely related hatchetfishes, Sternoptychidae, were taken in only slightly larger numbers at night (1.24 times as many as in day hauls). In the section dealing with depth distribution of fish larvae it was pointed out that the gonostomatid, *Vinciguerria* spp. occurred no deeper than ca. 130 m in NORPAC collections, whereas sternoptychid larvae were inhabitants of the aphotic zone below 130 m. An interesting exception should be noted: gonostomatid larvae of the subfamily Maurolicinae had depth distributions similar to sternoptychid larvae on NORPAC. Larvae of two Maurolicinae, *Maurolicus* and *Araiophos*, genera were taken on EASTROPAC. Although the depth distribution of these genera has not

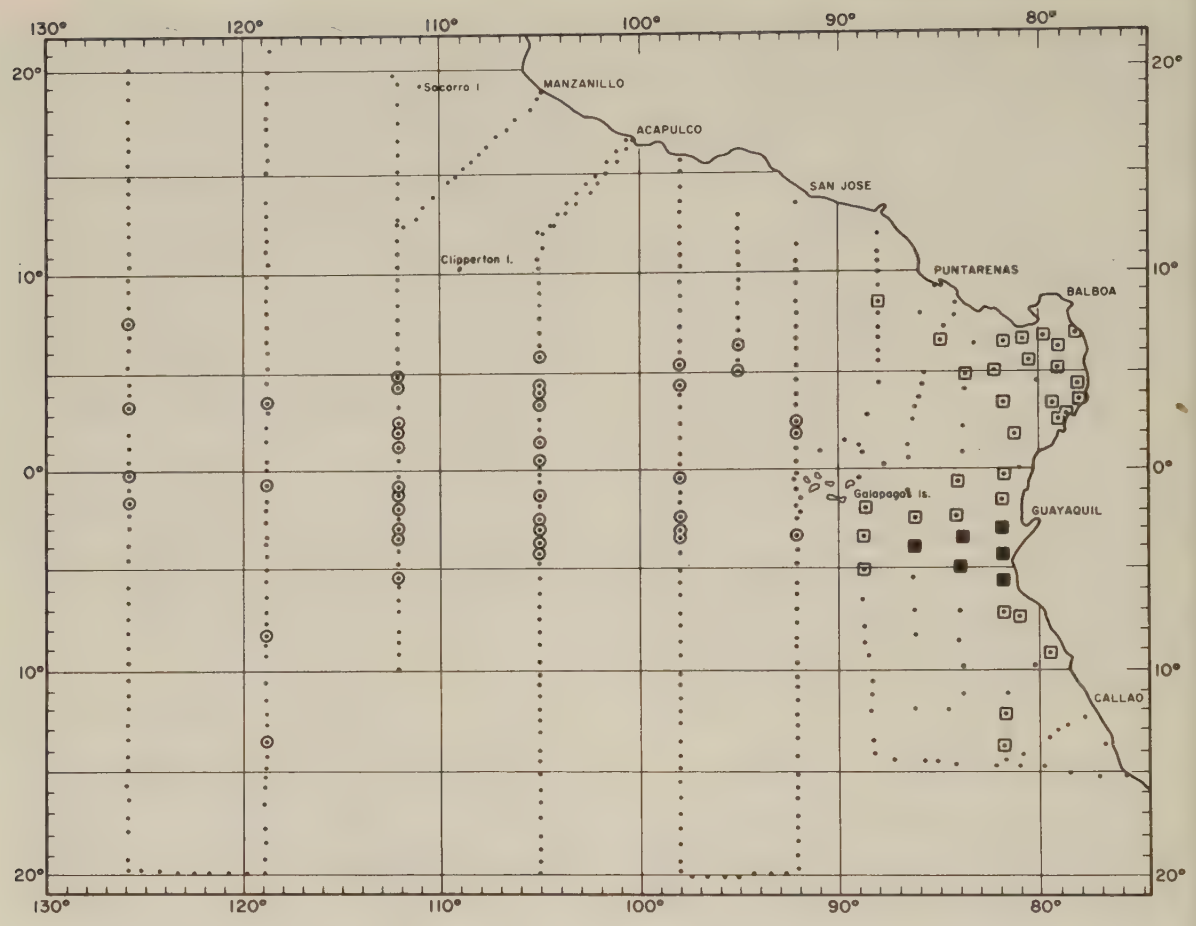


FIGURE 2.—Distribution of larvae of the argentinid, *Nansenia* spp., and of the bathylagid, *Leuroglossus stilbius urotranus* (Bussing) on EASTROPAC I. Records of occurrence of *Nansenia* larvae are shown as open circles with dot in center, while those of *Leuroglossus* larvae are open squares with dot (1 to 100 larvae) or closed squares (101 to 490 larvae). Small solid circles represent other stations occupied on EASTROPAC I.

TABLE 9.—Areal occurrence and relative abundance of larvae of Gonostomatidae on EASTROPAC I.

Latitude	*Argo* 11.000 series		*David Starr Jordan* 12.000 series		*Rockaway* 13.000 series		*Alaminos* 14.000 series		Total EASTROPAC I		
	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	Average no. larvae per positive haul
20° N-15° N	16	418	20	1,534	5	115	---	---	41	2,067	50.4
15° N-10° N	14	380	22	745	24	607	---	---	60	1,732	28.9
10° N- 5° N	13	185	13	242	27	2,085	14	417	67	2,929	43.7
5° N- 0°	14	2,112	15	637	14	1,825	27	1,882	70	6,456	92.2
0° - 5° S	14	409	18	912	14	1,577	16	1,036	62	3,934	63.5
5° S-10° S	13	202	14	161	14	799	10	647	51	1,809	35.5
10° S-15° S	14	635	8	368	15	524	21	490	58	2,017	34.8
15° S-20° S	20	322	8	183	22	597	---	---	50	1,102	22.0
Total	118	4,663	118	4,782	135	8,129	88	4,472	459	22,046	48.0

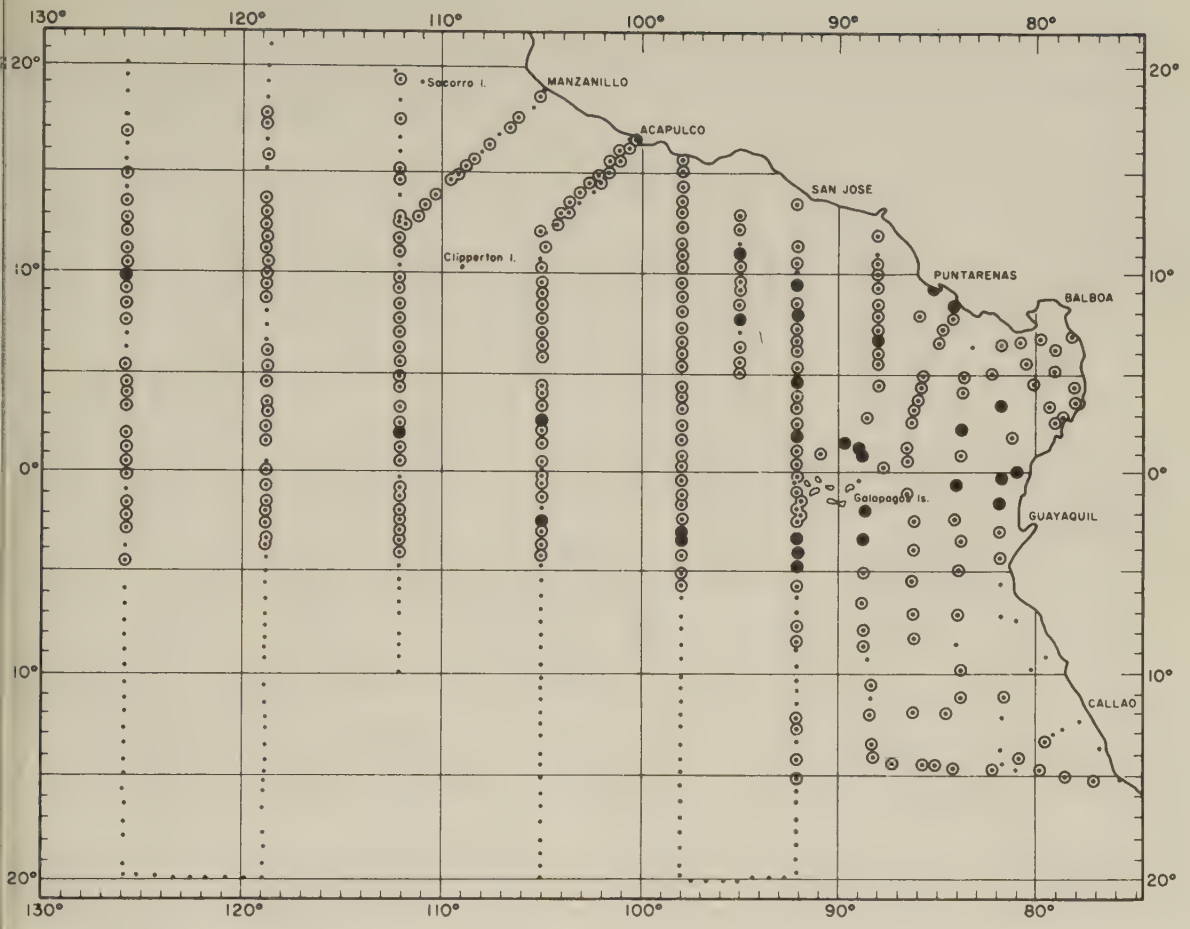


FIGURE 3.—Distribution of larvae of *Bathylagus nigrigenys* Parr on EASTROPAC I. Two orders of abundance are shown: open circles with dot in center represent counts of 1 to 25 larvae, large solid circles represent counts of 26 or more larvae. Small solid circles represent negative hauls.

been determined, they were sampled more fully during daylight hours than other gonostomatids; the night/day ratio for *Maurolicus* and *Araiophos* larvae was ca. 1.6 and 2.0 respectively.

Larvae belonging to six gonostomatid genera were common to abundant (Table 10) and larvae of several additional genera were taken occasionally. Larvae of two genera were of outstanding importance in the EASTROPAC area—*Vinciguerria* and *Cyclothone*. *Vinciguerria occurred* in 87.5 % of the collections, *Cyclothone* in 62.4 %.

Charts showing the distribution and relative abundance of larvae of Gonostomatidae and Sternoptychidae (combined) on EASTROPAC I will be included in the EASTROPAC Atlas.

Araiophos eastropas Ahlstrom and Moser (18 occurrences, 529 larvae)

Larvae of *Araiophos eastropas* were obtained only on the outermost pattern to the south of lat 10° S (Fig. 4). Within this limited area it was the most common gonostomatid. The species taken on EASTROPAC represented an undescribed species in a genus that previously

TABLE 10.—Frequency of occurrence and relative abundance of the kinds of gonostomatid larvae on EASTROPAC I.

Gonostomatid larvae	*Argo* 11.000 series		*David Starr Jordan* 12.000 series		*Rockaway* 13.000 series		*Alaminos* 14.000 series		Total EASTROPAC I	
	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae
Araiophos eastropas	18	529	0	0	0	0	0	0	18	529
Cyclothone spp.	94	697	71	582	89	735	47	167	301	2,181
Diplophos taenia	18	51	40	107	14	24	1	1	73	183
Ichthyococcus spp.	7	9	11	16	18	31	5	5	41	61
Maurolicus muelleri	0	0	11	43	19	143	13	78	43	264
Vinciguerria spp.	96	3,339	109	4,011	131	7,179	86	4,211	422	18,740
Other gonostomatids	13	38	9	23	12	17	8	10	42	88
Total	118	4,663	118	4,782	135	8,129	88	4,472	459	22,046

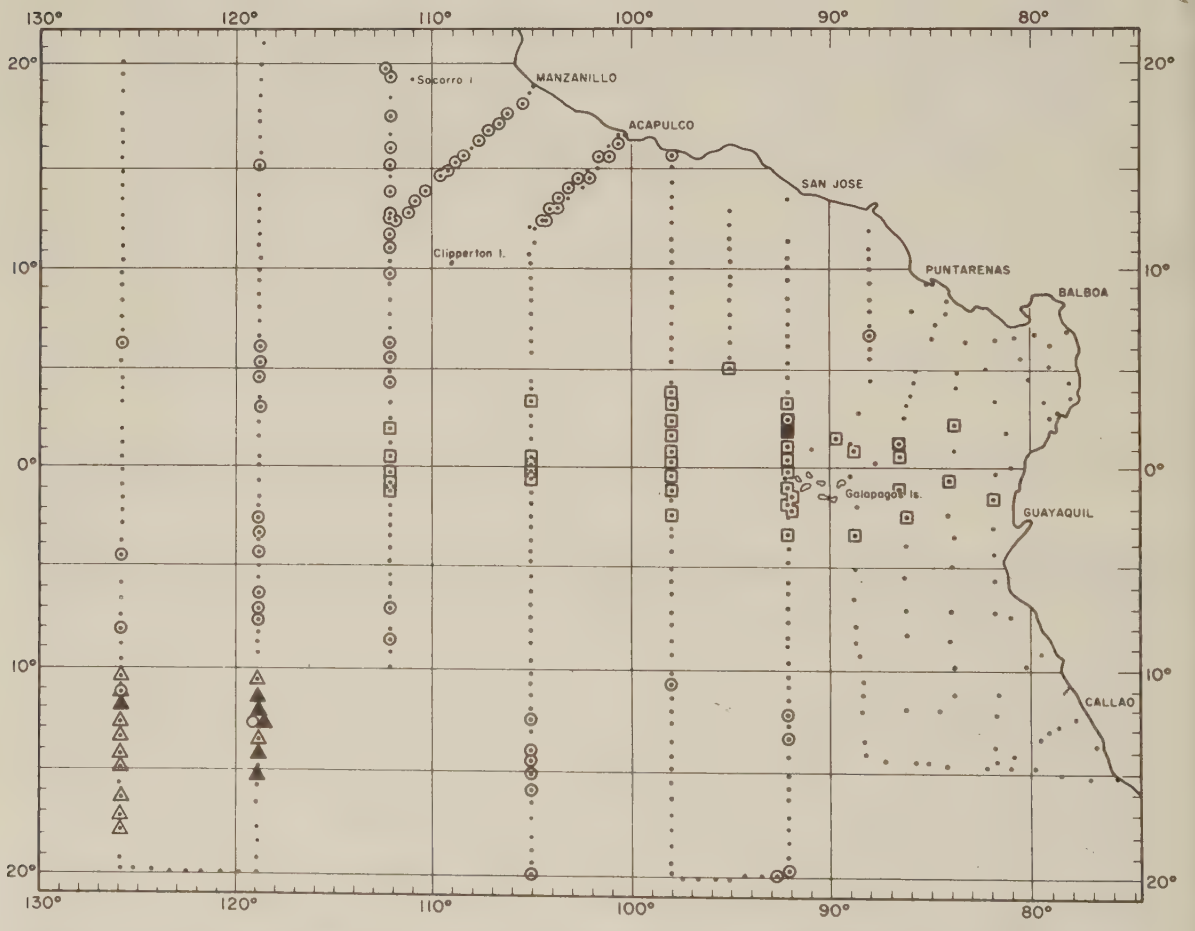


FIGURE 4.—Distribution of larvae of three species of Gonostomatidae on EASTROPAC I. Records of occurrence of larvae of *Araiophos eastropas* Ahlstrom and Moser are shown as triangles, *Diplophos taenia* (Günther) as large open circles, and *Maurolicus muelleri* (Gmelin) as squares. Solid triangles and squares are for counts of 26 or more larvae. Small solid circles represent negative hauls.

was known from a single collection made off Hawaii (Grey, 1961). Adults and larvae were described by Ahlstrom and Moser (1969).

Cyclothone spp. (301 occurrences, 2,181 larvae)

Larvae of *Cyclothone* spp. were taken least frequently in the northern quarter of the EASTROPAC pattern (betweeen lat 10° and 20° N, and in the inner pattern occupied by *Alaminos* (Table 11 and Fig. 5). In the former area, less than 20 % of the hauls (20 of 103) contained *Cyclothone* larvae; in the inshore pattern only about 45 % of the hauls (47 of 103) contained *Cyclothone* larvae. Over the remainder of the EASTROPAC I pattern *Cyclothone* larvae occurred at most stations (234 of 276). The lowest number of larvae per positive haul, 2.15 larvae, was obtained in the northern section; the next lowest, 3.55 larvae per positive haul, in the *Alaminos* pattern. Over the remainder of the pattern, 8.42 larvae were obtained per positive haul.

No attempt was made to identify the larvae of *Cyclothone* to species, and our hauls did not extend deep enough to collect adults.

Diplophos taenia Günther (73 occurrences, 183 larvae)

A study was made of larval and adult specimens of *Diplophos* in an attempt to determine whether the Pacific specimens should be assigned to *D. taenia* or retained as a distinct species, *D. pacificus* Günther. Grey (1960) had placed Pacific specimens in *D. taenia* but later she (Grey, 1964, p. 89) developed reservations because of the consistently lower photophore count of the ventral series in Pacific specimens. Without detailing my observations on *Diplophos*, which I plan to publish separately, I have concluded that our eastern Pacific *Diplophos* is not separable from the Atlantic *D. taenia*.

Larvae of *Diplophos* were taken most commonly to the north of lat 10° N—36 occurrences, 105 larvae (Fig. 4). The remaining 37 occurrences, 78 larvae were distributed throughout the EASTROPAC I pattern.

Ichthyococcus spp. (41 occurrences, 61 larvae)

Two kinds of *Ichthyococcus* larvae were taken on EASTROPAC I. The specific identity of the more common form has been determined as *I. irregularis* Rechnitzer and Böhlke; the other form has yet to be identified to species.

Maurolicus muelleri (Gmelin) (43 occurrences, 264 larvae)

Larvae of this species were taken only on an equatorial band between lat 5° N and 5° S and were not taken in the outer pattern occupied by *Argo* (Fig. 4). This distribution, without additional information, could be misleading. *Maurolicus* is known to have a wide latitudinal distribution in the South Pacific. For example, *Maurolicus* larvae were obtained at lat 33° S on MARCHILE VI, the portion of EASTROPAC II occupied by the Chilean vessel *Yelcho*. We also have collections from south of New Zealand, obtained on an *Eltanin* cruise. The species may be carried northward off South America in the Humboldt Current and then offshore in the equatorial current system.

TABLE 11.—Areal occurrence and relative abundance of larvae of *Cyclothone* spp. on EASTROPAC I.

Latitude	*Argo* 11.000 series		*David Starr Jordan* 12.000 series		*Rockaway* 13.000 series		*Alaminos* 14.000 series		Total EASTROPAC I		
	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	Average no. larvae per positive haul
20° N-10° N	12	31	4	8	4	4	--	--	20	43	2.2
10° N- 0°	24	136	25	137	33	235	23	69	105	577	5.5
0° -10° S	24	179	29	246	20	117	13	43	86	585	6.8
10° S-20° S	34	351	13	191	32	379	11	55	90	976	10.8
Total	94	697	71	582	89	735	47	167	301	2,181	7.2

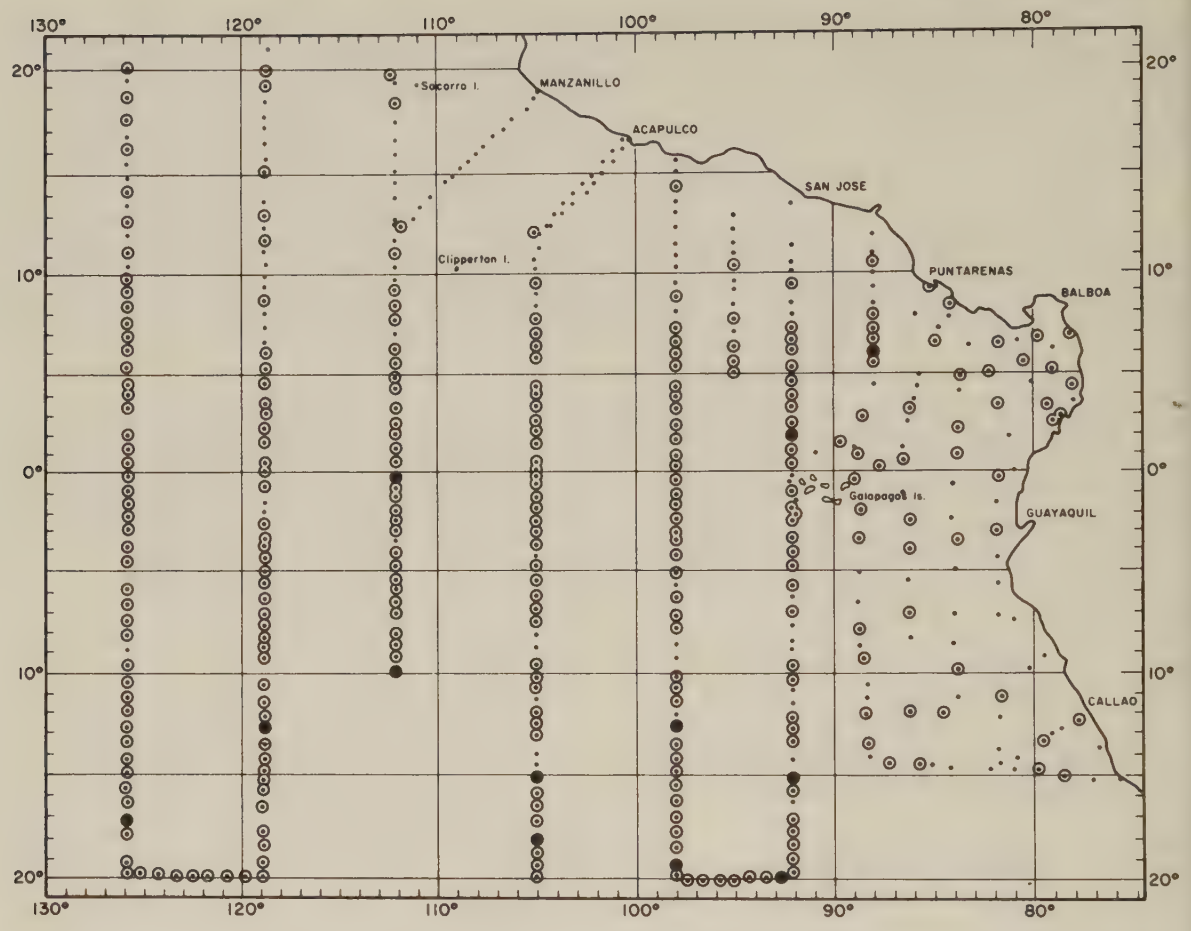


FIGURE 5.—Distribution of larvae of the gonostomatid *Cyclothone* spp. on EASTROPAC I. Collections of 1 to 25 larvae are shown as circles with dot in center, collections of 26 or more larvae as large solid circles; negative hauls are shown as small solid circles.

***Vinciguerria* spp. (422 occurrences, 18,740 larvae)**

Larvae of *Vinciguerria* occurred in more hauls than those of any other genus and ranked second in abundance to the myctophid genus *Diogenichthys*. The distribution of *Vinciguerria* larvae is shown in Figure 6. Although most of the material unquestionably is *V. lucetia* (Garman), some of the collections from offshore and particularly from the central South Pacific water mass between lat 5° and 20° S represent *V. nimbaria* (Jordan and Williams). The larvae of *V. nimbaria* are indistinguishable from those of *V. lucetia* (Ahlstrom and Counts, 1958), hence identification must be made on metamorphosing specimens, juveniles, and adults. The two species are closely allied, but readily separable from *V. poweriae* (Cocco) and *V. attenuata* (Cocco), the other two species of *Vinciguerria*, at all stages of development. A trenchant difference between the two "pairs" of species is the development of a pair of symphyseal photophores under the lower jaw in *V. lucetia* and *V. nimbaria* and the absence of this pair in *V. poweriae* and *V. attenuata*. The two characters most readily used for distinguishing

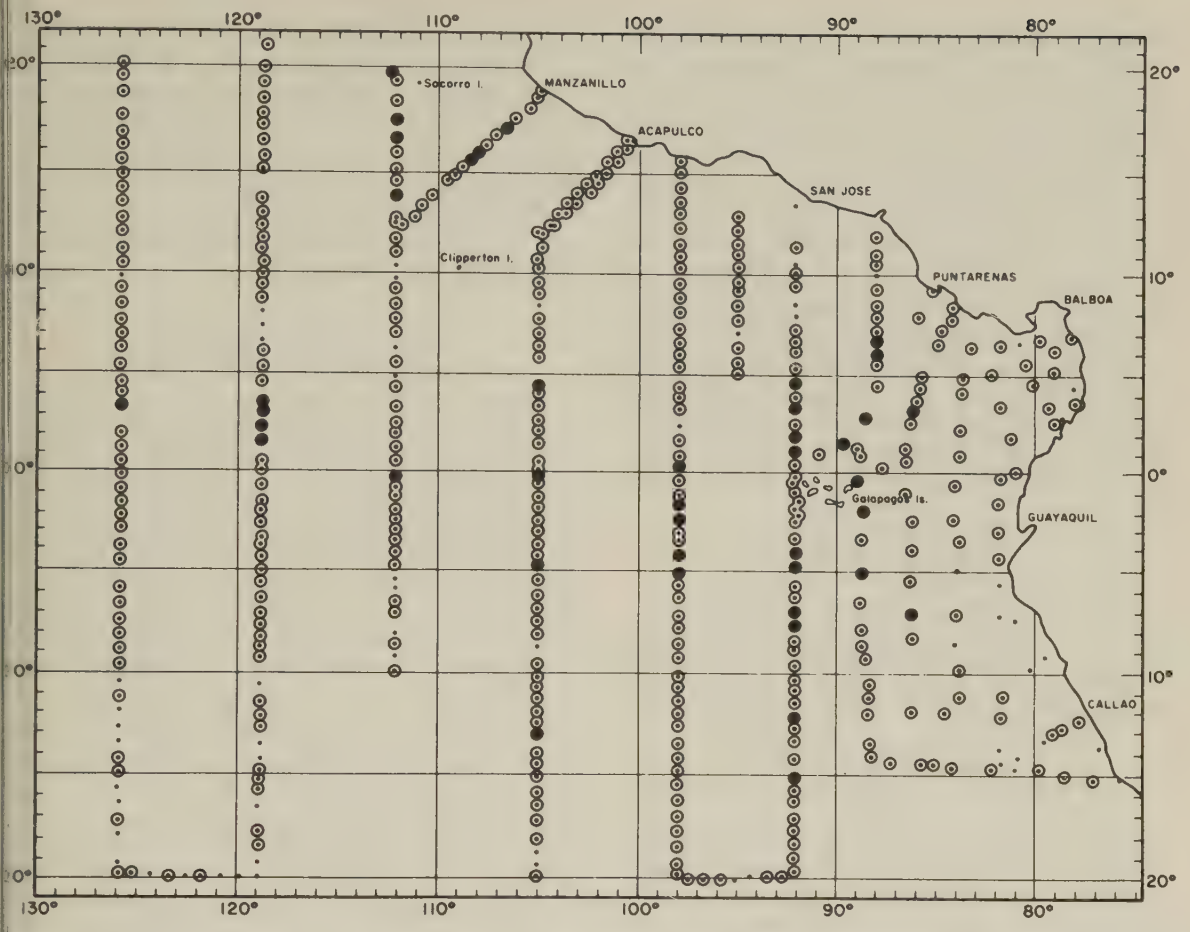


FIGURE 6.—Distribution of larvae of the gonostomatid, *Vinciguerria* spp. on EASTROPAC I. Collections of 1 to 100 larvae are shown as circles with dot in center, collections of 101 or more larvae as large solid circles; negative hauls are shown as small solid circles.

between *V. lucetia* and *V. nimbaria* are (1) number of gill rakers and (2) number of IV (and OV) photophores. Material of *V. nimbaria* studied from the eastern North Pacific (ibid.) had 5 to 6 + 15 gill rakers and 23 to 24 IV photophores (13 to 14 OV photophores) whereas *V. lucetia* had 8 to 10 + 18 to 23 gill rakers and 20 to 23 IV photophores (10 to 13 OV photophores). In the EASTROPAC area, *V. lucetia* maintained the high gill raker counts, but usually had 21 IV (11 OV) photophores. The offshore form referred to *V. nimbaria* usually had 22 IV (12 OV) photophores (1 less per group than in *V. nimbaria* from the temperate North Pacific) and 6 to 7 + 15 to 16 gill rakers (a slightly higher count).

In most areas the adults of the two species of *Vinciguerria* did not co-occur, hence the larvae can be assigned with some assurance to one or the other. For example, all collections made between lat 5° and 20° S from *Argo* and *Jordan* patterns were exclusively *V. nimbaria*. On these patterns the plankton hauls were supplemented by micronekton net hauls, and the latter contained material of *Vinciguerria* juveniles and adults from most stations occupied

at night. Unfortunately, the micronekton net was not used on *Rockaway* (12.000 series), and insufficient numbers of older stages (metamorphosing specimens and juveniles) were taken in plankton hauls to permit a meaningful separation of the two species in waters to the south of lat 5° S in this series.

Vinciguerria poweriae (Cocco) co-occurred with *V. nimbaria* in the central water mass of the North Pacific (Ahlstrom and Counts, 1958), but no material of *V. poweriae* was obtained in EASTROPAC collections. However, material of *V. attenuata* (Cocco) was obtained from farther south in the eastern Pacific on the "Downwind Expedition"—hence all four species of *Vinciguerria* do occur in the eastern Pacific.

Other gonostomatids (42 occurrences, 88 larvae)

Included in this category are larvae of two identified genera, *Gonostoma* and *Woodsia*, and several kinds of larvae that are unmistakably gonostomatid, but not identified as to kind.

6. STERNOPTYCHIDAE
(337 occurrences, 5,687 larvae)

Hatchetfish larvae ranked third in abundance (5.98 % of total), exceeded by larvae of Myctophidae and Gonostomatidae. The majority of hatchetfish larvae were those of *Sternoptyx diaphana* Hermann, and most of the remainder of *Argyropelecus lychnus* Garman. Because larvae of Sternoptychidae are more fragile than most other kinds and are usually in poor condition, no attempt was made to identify them to genus or species. Areal occurrence and relative abundance of sternoptychid larvae on EASTROPAC I are summarized in Table 12. Larvae were not only taken in markedly more collections between lat 10° N and 10° S—94 % of the collections were positive as compared with only 41 % in the remainder of the pattern—but more larvae were taken per positive haul—21.1 larvae as compared with 5.2.

7. ASTRONESTHIDAE
(12 occurrences, 13 larvae)

Several kinds of astronesthid larvae were collected in the EASTROPAC area: only one kind had heavy pigmentation on the body; the others were lightly, but characteristically pigmented. Larvae of Astronesthidae are similar in appearance to other stomiatoid larvae; they have a slender, elongated body, and a long intestine that underlies the body for about 7/10 or more of the standard length, and usually has a free terminal, trailing portion that can be quite long, often trailing beyond the caudal fin. Astronesthid larvae can be distinguished readily from other stomiatoid larvae by the forward position of the dorsal fin in relation to the anal fin. Developmental series of astronesthid larvae have not been described in literature. Eleven of the 12 occurrences of astronesthid larvae were taken within 10° ± of the equator.

8. CHAULIODONTIDAE
(80 occurrences, 165 larvae)

Larvae of *Chauliodus* are readily identifiable to genus, but are difficult to separate at the spe-

TABLE 12.—Areal occurrence and relative abundance of larvae of Sternoptychidae on EASTROPAC I.

Latitude	*Argo* 11.000 series		*David Starr Jordan* 12.000 series		*Rockaway* 13.000 series		*Alaminos* 14.000 series		Total EASTROPAC I		
	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	Average no. larvae per positive haul
20° N-15° N	8	44	0	0	0	0	--	--	8	44	5.5
15° N-10° N	6	41	3	31	9	66	--	--	18	138	7.7
10° N- 5° N	14	312	14	479	29	1,006	14	237	71	2,034	28.6
5° N- 0°	14	133	15	430	13	456	22	414	64	1,433	22.4
0° - 5° S	14	140	18	353	14	303	16	129	62	925	14.9
5° S-10° S	12	198	14	317	14	210	10	104	50	829	16.6
10° S-15° S	13	40	8	98	11	83	5	7	37	228	6.2
15° S-20° S	9	15	2	4	16	37	--	--	27	56	2.1
Total	90	923	74	1,712	106	2,161	67	891	337	5,687	16.9

cies level, because of lack of pigmentation. It has not been determined yet whether one or more species of *Chauliodus* occur in the EASTROPAC area. *Chauliodus* larvae were widely distributed, usually occurring singly (50 such occurrences). In only five hauls were six or more larvae obtained per haul; all of these were in the outer patterns occupied by *Jordan* and *Argo*.

9. IDIACANTHIDAE
(167 occurrences, 960 larvae)

It is not known definitely whether one or two species of *Idiacanthus* occur in the eastern Pacific; the problem hinges on whether *I. panamensis* is distinct from *I. antrostomus* Gilbert. Gibbs (1964) considered the two species to be "probably synonymous." In the EASTROPAC area, *Idiacanthus* occurred more frequently in the northern portion of the pattern, between lat 10° and 20° N, as is shown in Table 13.

10. OTHER STOMIATOIDEI
(203 occurrences, 502 larvae)

Larvae belonging to three families are included as other Stomiatoidei—i.e., of Stomiatidae, Melanostomiatidae, and Malacosteidae. The most common larva in this category, that of *Bathophilus filifer* (Garman) (86 occurrences, 227 larvae) is separately tabulated in Appendix Table 3. Larvae of *Eustomias*, representing several species, occurred in 17 collections. Larvae of *Stomias* were separately tabulated from only eight collections; however, a number of larvae tabulated as unidentified stomiatoid larvae undoubtedly are those of *Stomias*. According to Gibbs (1969), no fewer than three species of *Stomias* occur in the eastern Pacific. Many stomiatoid larvae were poorly preserved, and were not identifiable with any certainty.

11. SYNODONTIDAE
(10 occurrences, 41 larvae)

All but three specimens were taken in the inner pattern, occupied by *Alaminos*. Six of the seven occurrences in this pattern were at contiguous stations occupied off Ecuador and the Gulf of Panama (Fig. 7). Synodontidae are coastal forms. No attempt was made to identify the larvae to the species level.

12. CHLOROPHTHALMIDAE
(1 occurrence, 4 larvae)

The only record of *Chlorophthalmus* larvae was from station 13.052. Larvae in this sample ranged from 5.0 to 6.5 mm long. Pigmentation was limited to a large, single peritoneal pigment patch—and to a few small melanophores on the dorsal and ventral margin of the tail soon before the tip of the notochord. Two larger specimens of *Chlorophthalmus* were taken in the micronekton net hauls, a 23.0-mm specimen at station 14.018 and a 39.5-mm specimen at station 14.051. Pigment on both was limited to the peritoneal patch, and a midline melanophore over the hypural complex; otherwise both specimens were milky white, without scales. The larger specimen had the following fin counts: D. 11, A. 11, V. 9, P. 17. These are identical to counts given by Garman (1899) for his species, *C. mento* from the Gulf of Panama, to which our material probably is referable.

TABLE 13.—Areal occurrence and relative abundance of larvae of Idiacanthidae on EASTROPAC I.

Latitude	*Argo* 11.000 series		*David Starr Jordan* 12.000 series		*Rockaway* 13.000 series		*Alaminos* 14.000 series		Total EASTROPAC I		
	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	Average no. larvae per positive haul
20° N-10° N	18	107	34	379	17	149	--	--	69	635	9.2
10° N- 0°	11	19	7	10	14	65	20	56	52	150	2.9
0° -10° S	4	6	2	4	7	44	4	9	17	61	3.6
10° S-20° S	9	15	3	4	8	53	9	42	29	114	3.9
Total	42	147	46	395	46	311	33	107	167	960	5.7

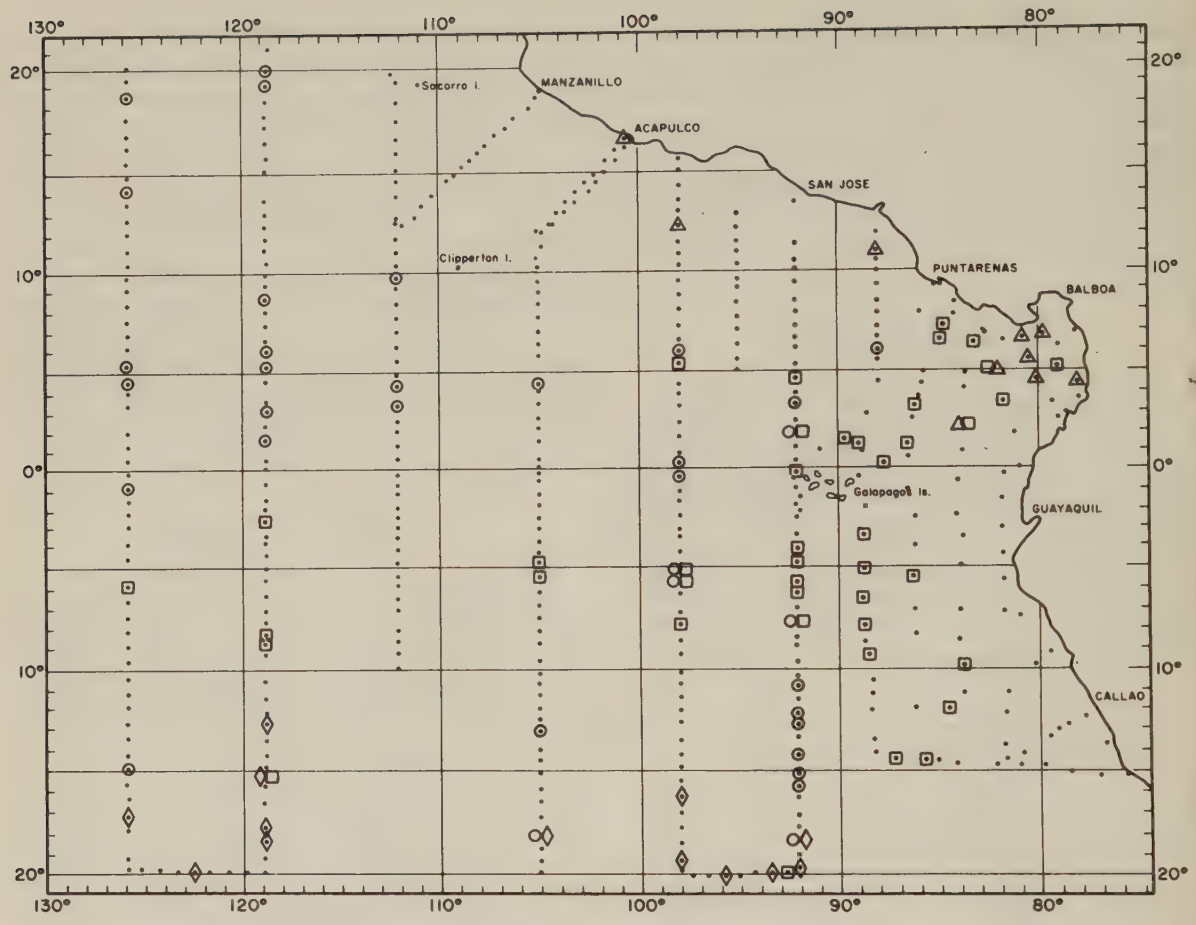


FIGURE 7.—Distribution of larvae of the paralepidids, *Macroparalepis macrurus* Ege and *Sudis atrox* Rofen, of *Synodus* spp., and of the gempylid *Nealotus tripes* Johnson on EASTROPAC I. Records of occurrence of larvae of *Macroparalepis macrurus* are shown as an open circle, larvae of *Sudis atrox* as a diamond, larvae of *Synodus* spp. as a triangle, and larvae of *Nealotus tripes* as a square; negative hauls are shown as small solid circles.

13. MYCTOPHIDAE
(472 occurrences, 44,913 larvae)

Myctophids made up 47.2% of the fish larvae taken on EASTROPAC I. Of the 482 oblique hauls taken on EASTROPAC I, 472 contained myctophid larvae. This dominant group occurred almost everywhere. However, as is shown in Table 14, larger numbers of myctophid larvae were taken per haul between lat 10° N and 5° S.

The myctophid fauna is a large one in numbers of genera and species represented in the eastern tropical Pacific. This diversity is shown in Table 15, in which occurrence and abundance of myctophid larvae are summarized by genus or species; the number of genera listed is 19. Even so, larvae of *Diogenichthys laternatus* made up over half of the total.

The study of larval myctophids is aided by the diversity of larval morphology found in this family, and by the fact that the larvae of most genera have a characteristic form that permits

identification to genus, even for genera in which the species composition has not been fully worked out. This point was stressed in two recent papers dealing with identification of myctophid larvae (Pertseva-Ostroumova, 1964; Moser and Ahlstrom, 1970).

Because of the importance of this group in the tropical ichthyoplankton, I will discuss its composition in more detail than for any other family except the Gonostomatidae.

Moser and Ahlstrom (1970) described developmental series for 14 species of lanternfishes with narrow-eyed larvae in the California Current. The following species also occur in the EASTROPAC area: *Electrona rissoi, Diogenichthys atlanticus, D. laternatus, Benthosema panamense, Hygophum atratum, H. reinhardti, Myctophum nitidulum, Loweina rara, Gonichthys tenuiculus,* and *Centrobranchus choerocephalus.*

TABLE 14.—Areal occurrence and relative abundance of larvae of Myctophidae on EASTROPAC I.

Latitude	*Argo* 11.000 series		*David Starr Jordan* 12.000 series		*Rockaway* 13.000 series		*Alaminos* 14.000 series		Total EASTROPAC I		
	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	Average no. larvae per positive haul
20° N-15° N	16	430	20	1,000	5	116	--	--	41	1,546	37.7
15° N-10° N	14	568	23	1,444	24	2,826	--	--	61	4,838	79.3
10° N- 5° N	14	1,323	14	2,136	29	5,856	15	2,730	72	12,045	167.3
5° N- 0°	14	1,988	15	2,327	14	1,325	27	6,075	70	11,715	167.4
0° - 5° S	14	1,233	18	3,413	14	1,635	16	1,209	62	7,490	120.8
5° S-10° S	13	567	15	408	14	994	13	635	55	2,604	47.3
10° S-15° S	14	563	8	296	15	1,362	25	768	62	2,989	48.2
15° S-20° S	19	321	8	250	22	1,115	--	--	49	1,686	34.4
Total	118	6,993	121	11,274	137	15,229	96	11,417	472	44,913	95.2

TABLE 15.—Summary, by genus or species, of occurrences and relative abundance of myctophid larvae in the four vessel patterns occupied on EASTROPAC I.[1]

Myctophid larvae	*Argo* 11.000 series		*David Starr Jordan* 12.000 series		*Rockaway* 13.000 series		*Alaminos* 14.000 series		Total EASTROPAC I	
	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae
Benthosema panamense	0	0	1	63	5	918	1	46	7	1,027
Centrobranchus spp.	0	0	3	4	0	0	0	0	3	[2]4
Ceratoscopelus townsendi-complex	46	235	24	140	42	633	5	12	117	1,020
Diaphus spp.	62	490	96	1,363	72	949	21	71	251	2,873
Diogenichthys laternatus	69	2,202	89	5,259	92	9,089	89	8,775	339	25,325
Diogenichthys atlanticus	3	4	6	11	18	75	2	2	29	92
Electrona sp.	5	6	9	34	19	34	0	0	33	74
Gonichthys tenuiculus	5	8	20	56	39	101	28	67	92	232
Gonichthys sp.	0	0	0	0	0	3	0	0	3	3
Hygophum atratum & H. reinhardti	30	177	52	352	37	268	8	90	127	887
Hygophum proximum	67	611	30	215	19	72	0	0	116	898
Lampadena spp.	13	27	10	21	15	71	0	0	38	119
Lampanyctus spp.	99	1,240	96	2,063	107	1,347	74	1,232	376	5,882
Lepidophanes pyrsobolus-complex	7	26	14	109	10	22	3	6	34	163
Lobianchia sp.	2	14	2	3	12	22	0	0	16	39
Loweina rara	18	25	7	11	13	14	4	5	43	56
Myctophum spp.	52	624	48	323	47	160	40	286	187	1,393
Nannobrachium valdiviae	40	210	47	290	60	344	11	24	158	868
Notoscopelus resplendens	13	37	21	104	21	73	15	69	70	283
Protomyctophum sp.	3	4	19	37	14	37	0	0	36	78
Symbolophorus evermanni	71	535	47	248	58	381	36	318	212	1,482
Triphoturus spp.	17	33	25	82	54	256	44	135	140	506
Unidentified myctophid larvae	39	98	36	65	62	190	26	56	163	409
Disintegrated myctophid larvae	75	387	60	423	64	170	42	223	241	1,203
Total myctophid larvae	118	6,993	121	11,274	137	15,229	96	11,417	472	44,913

[1] The table summarizes the data presented by individual station in Appendix Table 2.
[2] *Centrobranchus* larvae are included under unidentified myctophid larvae in Appendix Table 2.

Benthosema panamense (Tåning) (7 occurrences, 1,027 larvae)

The relatively large number of larvae taken in a few hauls probably results from the adults of this species occurring in more compact aggregations than other myctophids (Alverson, 1961). All occurrences were within a few hundred miles of the coast, mostly off Mexico and Costa Rica. Distribution of larvae of *B. panamense* in the eastern tropical Pacific was illustrated in Moser and Ahlstrom (1970).

Centrobranchus spp. (3 occurrences, 4 larvae)

The larvae assigned to *Centrobranchus* represent two kinds; one of these is identical to the larvae described as *C. choerocephalus* (Moser and Ahlstrom, 1970). The other is possibly *C. andrae.*

Ceratoscopelus townsendi-complex (117 occurrences, 1,020 larvae)

Until recently, only two species of *Ceratoscopelus* were recognized: *C. townsendi* (Eigenmann and Eigenmann) and *C. maderensis* (Lowe). The larvae of these two species are distinctively different, especially in pigmentation. Nafpaktitis and Nafpaktitis (1969) concluded that *C. warmingi* (Lutken) was distinct from *C. townsendi* and was the more widely distributed species. They indicated that *C. townsendi* probably was restricted in its distribution to the eastern North Pacific. The major difference between the two species is the presence on *C. townsendi* of a large patch of luminous tissue along the dorsal rim of the orbit on specimens larger than ca. 21 mm SL; otherwise, the two species are almost identical in meristic characters, arrangement of photophores, and the placement of most luminous patches.

Subsequent to the publication of the paper by Nafpaktitis and Nafpaktitis (1969), my colleague, H. G. Moser, and I studied developmental series of *Ceratoscopelus* larvae previously assigned to *C. townsendi.* Moser (unpublished) studied eastern North Pacific material (CalCOFI and NORPAC) and material from the eastern South Pacific obtained on EASTROPAC I; I had the opportunity to examine a number of collections of *Ceratoscopelus* larvae collected by the *Meteor* in the Indian Ocean (through the generosity of W. Nellen of the Institut für Meereskunde, University of Kiel, Germany). Based on criteria of Nafpaktitis and Nafpaktitis, adults from both the Indian Ocean and southern portion of the EASTROPAC area were referable to *C. warmingi,* those from CalCOFI and NORPAC to *C. townsendi.* Larvae from the three regions were strikingly similar in appearance. Observed differences were mostly in rate of development, particularly in the sizes at which fin formation took place and at which photophores developed. Even so, somewhat greater differences were observed between *Ceratoscopelus* larvae from the Indian Ocean and those from the EASTROPAC area, than between larvae from the two eastern Pacific regions. For the present, I choose to call attention to the complexity of this problem by referring EASTROPAC material to the *C. townsendi*-complex.

Distribution of *C. townsendi*-complex larvae on EASTROPAC I is illustrated in Figure 8. Most occurrences were in offshore waters between lat 5° and 20° S, i.e., in the South Pacific central water mass. *Ceratoscopelus* larvae are known to have a complementary distribution in the eastern North Pacific. On the NORPAC Expedition *Ceratoscopelus* larvae were the dominant myctophid in the North Pacific central water mass between ca. lat 20° and 40° N. The occurrences of *Ceratoscopelus* larvae in the *Argo* pattern between lat 17° and 20° N are a fragment of this northern population. The few occurrences of *Ceratoscopelus* larvae in waters of the equatorial current system were small individuals. A few adults also were collected in this region, hence tropical waters may not be a barrier to the interchange of fish between the populations in the North and South Pacific.

Diaphus spp. (251 occurrences, 2,873 larvae)

Diaphus, the genus of myctophids with the largest number of species, is represented in the tropical eastern Pacific by a number of larval forms whose specific identities have been worked out only partially.

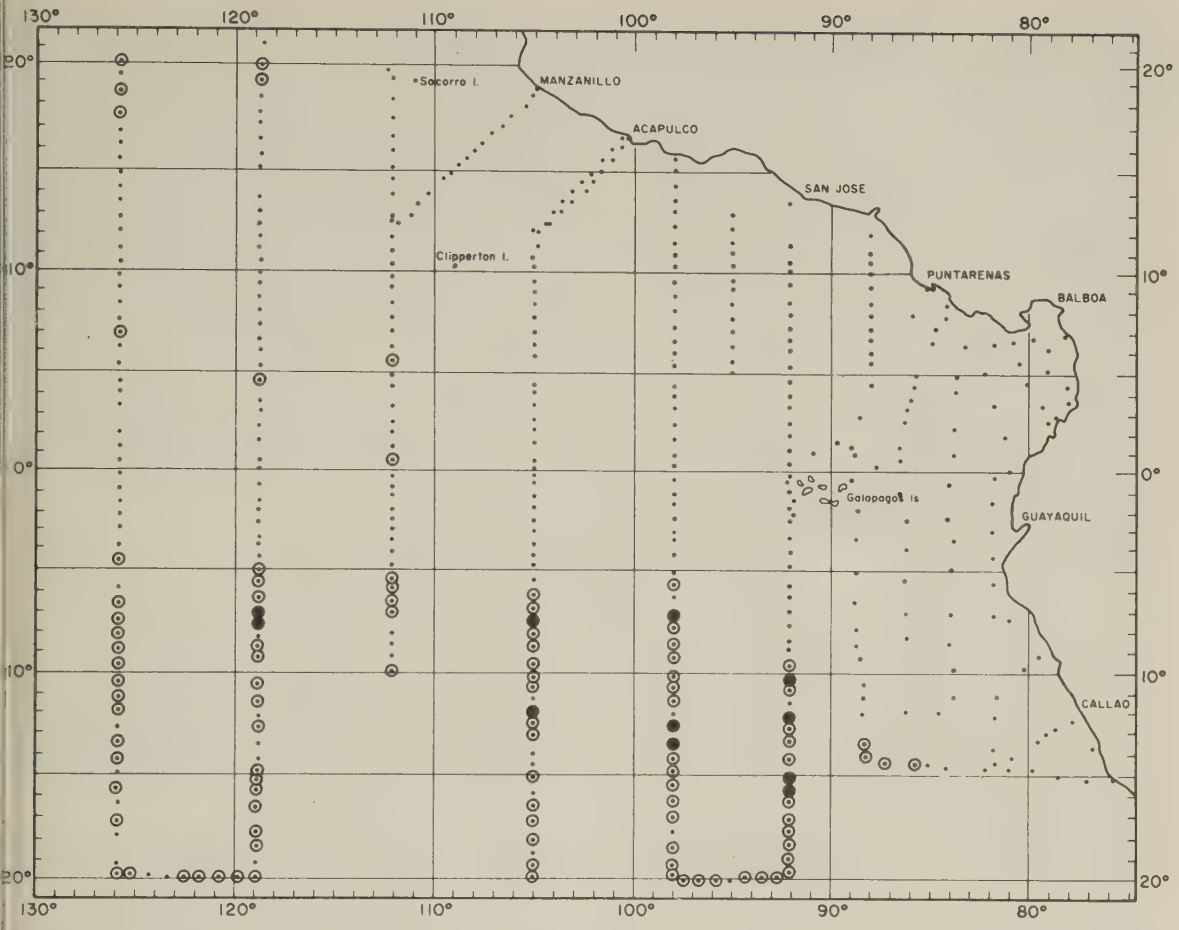


FIGURE 8.—Distribution of larvae of the myctophid, *Ceratoscopelus townsendi*-complex on EASTROPAC I. Collections of 1 to 25 larvae are shown as circles with dot in center, collections of 26 or more larvae as large solid circles; negative hauls are shown as small solid circles.

The genus *Diaphus* is not a natural assemblage, inasmuch as there are two distinctive larval morphs for the species in the EASTROPAC area. One group has slender-bodied larvae with persistent ventral midline pigment on the tail; the adults of this group possess both Vn and So occular photophores (subgenus *Diaphus* of Fraser-Brunner, 1949). The other and larger group has stubby-bodied larvae which usually are but lightly pigmented; in the EASTROPAC area the larvae of *Diaphus pacificus* Parr is a representative example.

Although *Diaphus* larvae were distributed over most of the area covered on EASTROPAC I, they were least common in the inner pattern occupied by *Alaminos* (21 occurrences, 71 larvae) and most consistently taken in the intermediate pattern occupied by *Jordan* (96 occurrences, 1,363 larvae).

Diogenichthys laternatus (Garman) (339 occurrences, 25,325 larvae)

Although this is by far the most abundant kind of larva taken on EASTROPAC I, it did not occur in the central water mass of the South

Pacific (Fig. 9). This species similarly is absent from the central water mass of the North Pacific (Moser and Ahlstrom, 1970). There is a striking similarity in the distributions of larvae of *D. laternatus* and those of *Bathylagus nigrigenys* Parr (Fig. 3) in the EASTROPAC area. *D. laternatus* is one of the smaller species of myctophids, measuring only 20.0 to 30.0 mm as adults; hence its biomass probably is not as great as its larval abundance would suggest.

Diogenichthys atlanticus (Tåning)
(29 occurrences, 92 larvae)

In contrast to its cogener, larvae of *Diogenichthys atlanticus* were taken mostly in the central water mass of the South Pacific on EASTROPAC I (Fig. 9). Most of the occurrences were to the south of lat 10° S on three adjacent lines (along long 92°, 98°, and 115° W). Two occurrences at the southern end of the *Alaminos* pattern, however, indicate that this

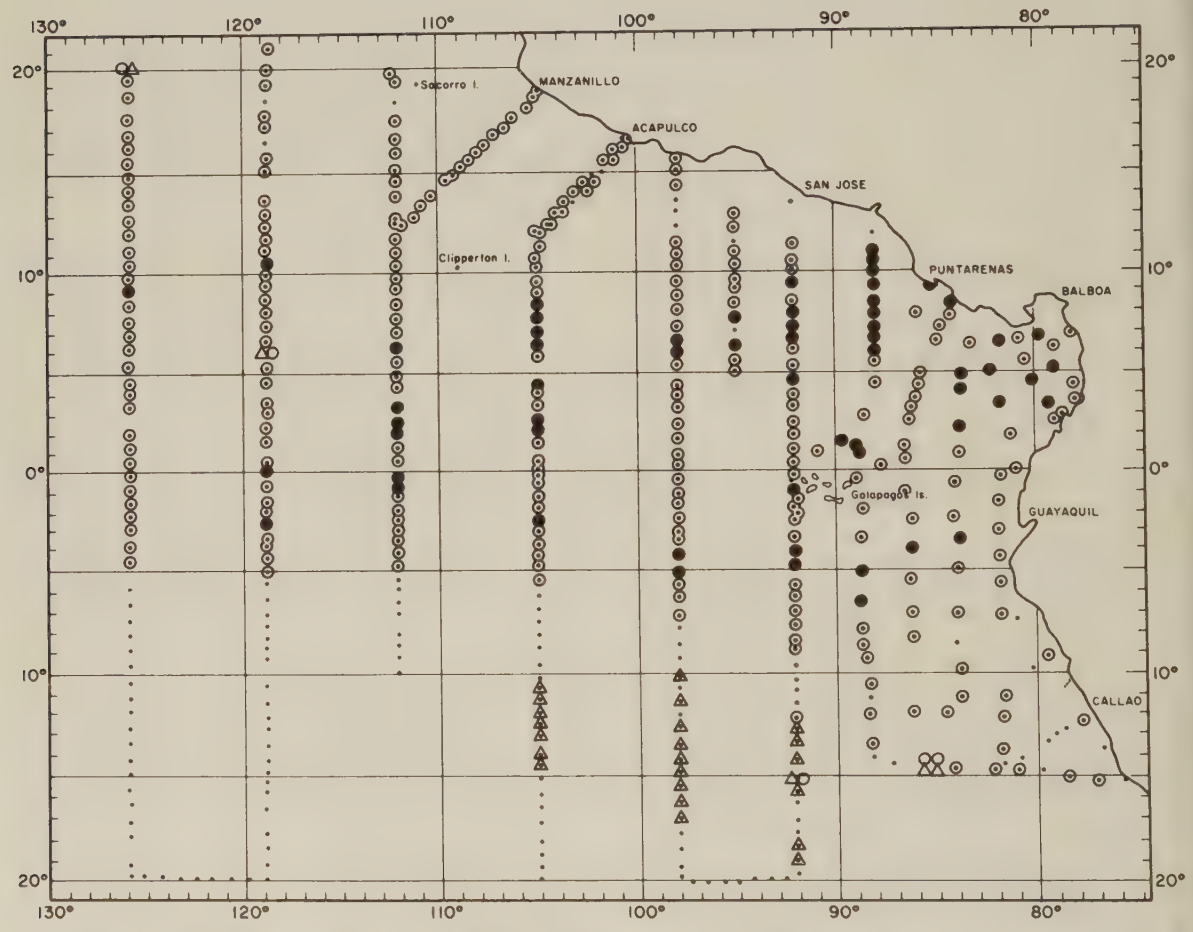


FIGURE 9.—Distribution of larvae of two species of myctophids of the genus *Diogenichthys* on EASTROPAC I. Records of occurrence of larvae of *D. atlanticus* (Tåning) are shown as triangles, records of occurrences of larvae of *D. laternatus* (Garman) as large circles with dot in center for hauls containing 0 to 100 larvae, and as large solid circles for hauls containing 101 or more specimens of this species; negative hauls are shown as small solid circles.

species is not restricted to the central water mass but also can occur in the transitional waters of the Humboldt Current. Larvae of this species were taken close to the Chilean coast between lat 20° and 30° S on MARCHILE VI, the Chilean contribution to EASTROPAC II. *D. atlanticus* appears to be a temperate-subtropical species, whereas *D. laternatus* is a tropical-subtropical species. The distribution of larvae of this species in the eastern North Pacific is given in Moser and Ahlstrom (1970, figs. 41 and 42). A larval specimen taken at lat 6° N along long 119° W shows that this species can bridge the tropical gap between its areas of usual occurrence in more temperate waters of the North and South Pacific.

***Electrona* sp. (33 occurrences, 74 larvae)**

Distribution of *Electrona* larvae on EASTROPAC I was limited to two bands—one centering on lat 5° N (6 occurrences, 16 larvae) the other in the central water mass of the South Pacific, between lat 8° and 20° S (27 occurrences, 58 larvae). The *Electrona* larvae all resemble *E. rissoi*, although two kinds may be present.

***Gonichthys tenuiculus* (Garman) (92 occurrences, 232 larvae)**

Larvae of *Gonichthys tenuiculus* have a similar distribution in the eastern tropical Pacific to those of *Diogenichthys laternatus*. Larvae of a different species of *Gonichthys* (3 occurrences, 3 larvae) were obtained at the southern end of the *Rockaway* pattern. Beebe and Vander Pyl (1944) reported collecting more adults of *G. tenuiculus* (reported as *Myctophum coccoi* (Cocco)), than of any other myctophid on the Arcturus Expedition to the eastern Pacific in 1925. Their collections were made on adults aggregating at the surface. Based on larval evidence, *Gonichthys tenuiculus* is only moderately common.

***Hygophum atratum-reinhardti* (127 occurrences, 887 larvae)**

Larvae of these two species are similar in appearance and difficult to distinguish at some stages of larval development. Larvae of *Hygophum atratum* (Garman) were distributed over much of the EASTROPAC pattern; however some occurrences at the southern end of the patterns of *Rockaway, Jordan,* and *Argo* were referable to *H. reinhardti* (Lutken).

***Hygophum proximum* Becker (116 occurrences, 898 larvae)**

Hygophum proximum is a truly oceanic species, not occurring at all in the inner pattern worked by *Alaminos,* and it was most abundant in the outer pattern occupied by *Argo* (Fig. 10). It occurs in the central water masses of the North and South Pacific, but also in the equatorial current system; the largest collection of larvae (103 specimens) was obtained at the equator.

***Lampadena* spp. (38 occurrences, 119 specimens)**

Two and possibly three kinds of *Lampadena* larvae were obtained on EASTROPAC. A developmental series definitely has been established for only one species, *Lampadena urophaos* Paxton. The relatively few occurrences of *Lampadena* larvae on EASTROPAC I were mostly in the southern portion of the three outer vessels (24 of 38 occurrences) and most of the remainder in an offshore band lying between lat 4° and 8° N (9 occurrences).

***Lampanyctus* spp. (376 occurrences, 5,882 larvae)**

Larvae of *Lampanyctus* were taken in more collections than those of any other myctophid genus but were not identified to species. A number of species of *Lampanyctus* occur in the EASTROPAC area, of which *L. idostigma* Parr, L. *omostigma* Gilbert, *L. parvicauda* (Parr), and *L. steinbecki* Bolin are among the more common. Larval series are being worked out for these.

***Lepidophanes* sp. (34 occurrences, 163 larvae)**

The species of *Lepidophanes* that occur in the EASTROPAC area belong to the *Lepidophanes*

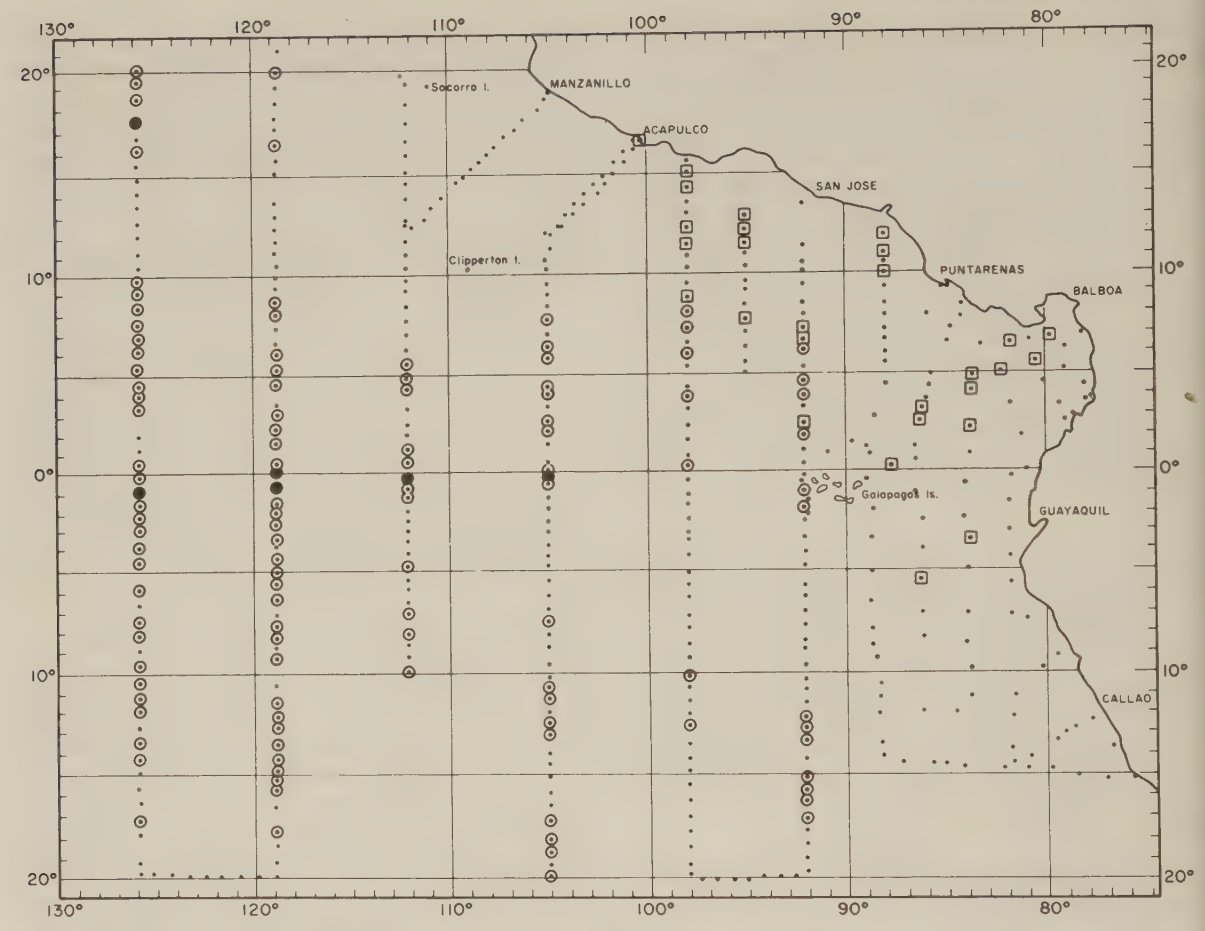


FIGURE 10.—Distribution of larvae of the myctophid *Hygophum proximum* (Becker) and of the bothid flatfish *Bothus leopardinus* (Günther) on EASTROPAC I. Records of occurrence of larvae of *H. proximum* are shown as open circles with dot in center for hauls containing 1 to 25 larvae, and as large solid circles for hauls containing 26 or more larvae; records of occurrence of larvae of *B. leopardinus* are shown as squares; negative hauls are shown as small solid circles.

pyrsobolus (Alcock) complex. Larvae of *Lepidophanes* are almost unpigmented, big eyed, and moderately deep bodied. They have few distinctive characters and can be confused with larvae of *Diaphus* and *Ceratoscopelus*. The majority of the records for *Lepidophanes* were of large larvae.

Lobianchia sp. (16 occurrences, 39 larvae)

Larvae of *Lobianchia* were not recognized until the identification of EASTROPAC larvae was well underway, hence our records of occurrences may be incomplete (some but not all samples were rechecked subsequently). The head of *Lobianchia* larvae is more massive than in most myctophid larvae. The most diagnostic feature, however, is the unusual manner in which the pectoral fins develop: the upper fin rays in each pectoral develop sooner than the remainder of the fin rays and become conspicuously elongated (Tåning, 1918). Twelve of the 16 occurrences were in the pattern worked by *Alaminos* and half of these were at adjacent

tations located between lat 6° and 2° N along ong 92° W.

Loweina rara (Lutken) (43 occurrences, 56 larvae)

The larger larvae of *Loweina rara* are among he most elegant of myctophid larvae. Larvae f this species were rather uncommon in the ASTROPAC area, although widely distributed. arvae were taken most frequently, however, in he vicinity of the equator, between ca. lat 8° N nd 7° S; 36 of the 43 occurrences were in the quatorial zone. The largest collection of *Lo-eina* larvae was only four specimens, and only single specimen was obtained in most collec-ons (i.e., in 35 of 43). The distribution of rvae of *L. rara* on EASTROPAC I is illus-ated in Moser and Ahlstrom (1970).

Myctophum spp. (187 occurrences, 1,393 larvae)

Myctophum is one of the more abundant gen-a represented in the eastern tropical Pacific. uvenile and adults of five species were ob-ained in 1-m plankton hauls and micronekton et hauls: *Myctophum aurolaternatum* Gar-an, *M. asperum* Richardson, *M. brachygnathos* Bleeker), *M. lychnobium* Bolin, and *M. nitid-lum* Garman. Body form and pigmentation of e five of six kinds of *Myctophum* larvae taken EASTROPAC I are as diverse as has been bserved within a myctophid genus. Larvae of . *nitidulum*, described by Moser and Ahlstrom 1970), are broad headed and deep bodied with es on short stalks; larger larvae of this spe-es are among the most heavily pigmented yctophid larvae.

A quite different developmental pattern is dis-ayed by larvae of *M. asperum* and *M. brachyg-thos*. The larvae of these species are also ep bodied and big headed, but the eyes are t borne on stalks. The most characteristic ature of the development of these larvae is e early appearance of Dn photophores which rm on larvae between 4.0 to 5.0 mm in length, on after the appearance of the Br_2 photo-ores. Larvae of *M. asperum* develop large aracteristic melanophores (Pertseva-Ostrou-mova, 1964), but larvae of *M. brachygnathos* are only slightly pigmented.

Larvae of *M. lychnobium* also are but lightly pigmented; they are much more slender and elongated than larvae of *M. brachygnathos* and do not develop the Dn photophores early. A notable feature is the marked length of the tear-drop (choroid) tissue that develops under the eyes (as long as in *Gonichthys* or *Centrobranchus* larvae).

The extraordinary larvae of *M. aurolaterna-tum* were only recently recognized and are not included in the above counts of *Myctophum*.

Notolychnus valdiviae (Brauer) (158 occurrences, 868 larvae)

This is probably the smallest species of myc-tophid, and certainly one of the most widespread in offshore, oceanic waters. The larvae seldom occur in large numbers (average number per positive haul was 5.5 larvae). They were present in about one-third of the collections made on EASTROPAC I, although most occur-rences were farther offshore than 300 miles of the coast (Fig. 11). Juvenile and adult *N. val-diviae* were frequently taken in the oblique plankton hauls. Perhaps as many juvenile and adult specimens of *N. valdiviae* were obtained by this means as of all other myctophids com-bined. Since this species has only a middling rank with regard to abundance of larvae, the frequency of capture of adults is probably less a measure of abundance than of their shallow depth distribution and poor swimming ability.

Notoscopelus resplendens (Richardson) (70 occurrences, 283 larvae)

This is the species of *Notoscopelus* known to occur in the eastern Pacific. On EASTROPAC, *Notoscopelus* larvae were taken more frequently and in larger numbers in the equatorial zone between lat 5° N and 5° S (40 occurrences, 209 larvae).

Protomyctophum sp. (36 occurrences, 78 larvae)

All occurrences of *Protomyctophum* larvae, except one, were between lat 10° N and 5° S.

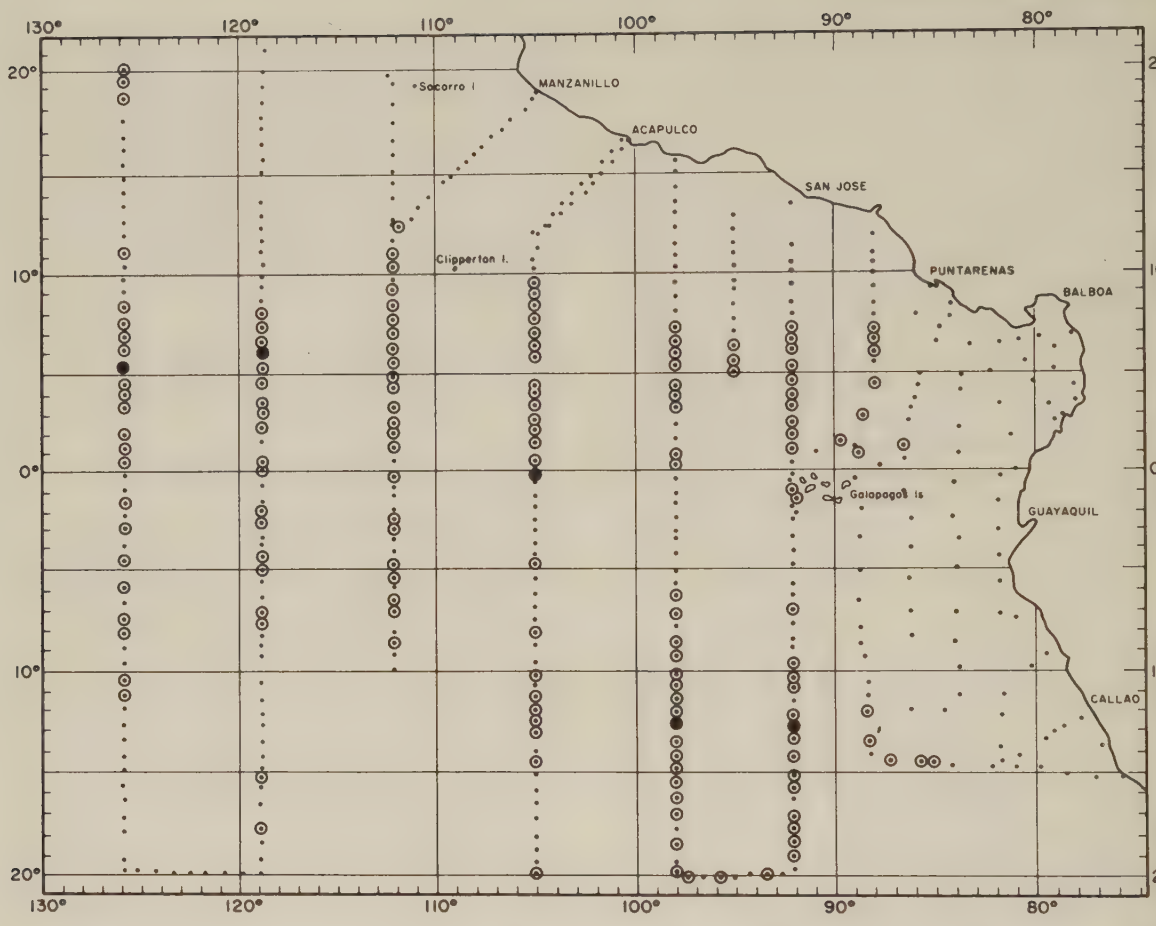


FIGURE 11.—Distribution of larvae of the myctophid, *Notolychnus valdiviae* (Brauer) on EASTROPAC I. Collections of 1 to 25 larvae are shown as circles with dot in center, collections of 26 or more larvae as large solid circles; negative hauls are shown as small solid circles.

Only one kind of *Protomyctophum* larva, belonging to the subgenus *Hierops*, was taken on EASTROPAC. The specific identity is unknown, as no juveniles or adults were obtained. The larva has a single lateral pigment spot per side over the gut, resembling in this respect the larva of *P. crockeri* (Bolin) (Moser and Ahlstrom, 1970). However, internal pigment develops over the hypural bones of the caudal complex in older larvae—resembling in this respect the pigmentation of older larvae of *P. thompsoni* (Chapman). The tropical form lacks ventral pigment on the tail posterior to the anus, such as is developed on larvae of *P. thompsoni*, and probably represents an undescribed species.

Symbolophorus evermanni (Gilbert) (212 occurrences, 1,482 larvae)

Only one kind of *Symbolophorus* larvae appears to be present in the EASTROPAC survey area, despite its distribution in different water masses including the central water mass of the South Pacific. Fewest occurrences were in the northern portion of the EASTROPAC pattern, between lat 10° and 20° N. The number of lar-

vae per positive haul ranged from 1 to 72 (average 7.0); 15 collections contained 25 or more larvae, most distributed between lat 7° and 20° S. Distribution of the larvae of *S. evermanni* on EASTROPAC I is illustrated in Figure 12.

Triphoturus spp. (140 occurrences, 506 larvae)

Larvae of at least two species of *Triphoturus* were taken in the EASTROPAC area. Of particular interest are larvae of *Triphoturus oculeus* (Garman); this species previously was considered a synonym of *T. mexicanus* (Gilbert), but larvae of the two species are differently pigmented. *T. oculeus* occurs in a broad coastal band between Panama and Chile, having in this respect a complementary distribution of that of *T. mexicanus* off California and Baja California.

14. PARALEPIDIDAE (290 occurrences, 1,648 larvae)

Larvae of Paralepididae were taken in approximately 60 % of the stations occupied on EASTROPAC I. The area of heaviest concentrations was in an equatorial band between lat 5° N and 5° S (Table 16). Two species are

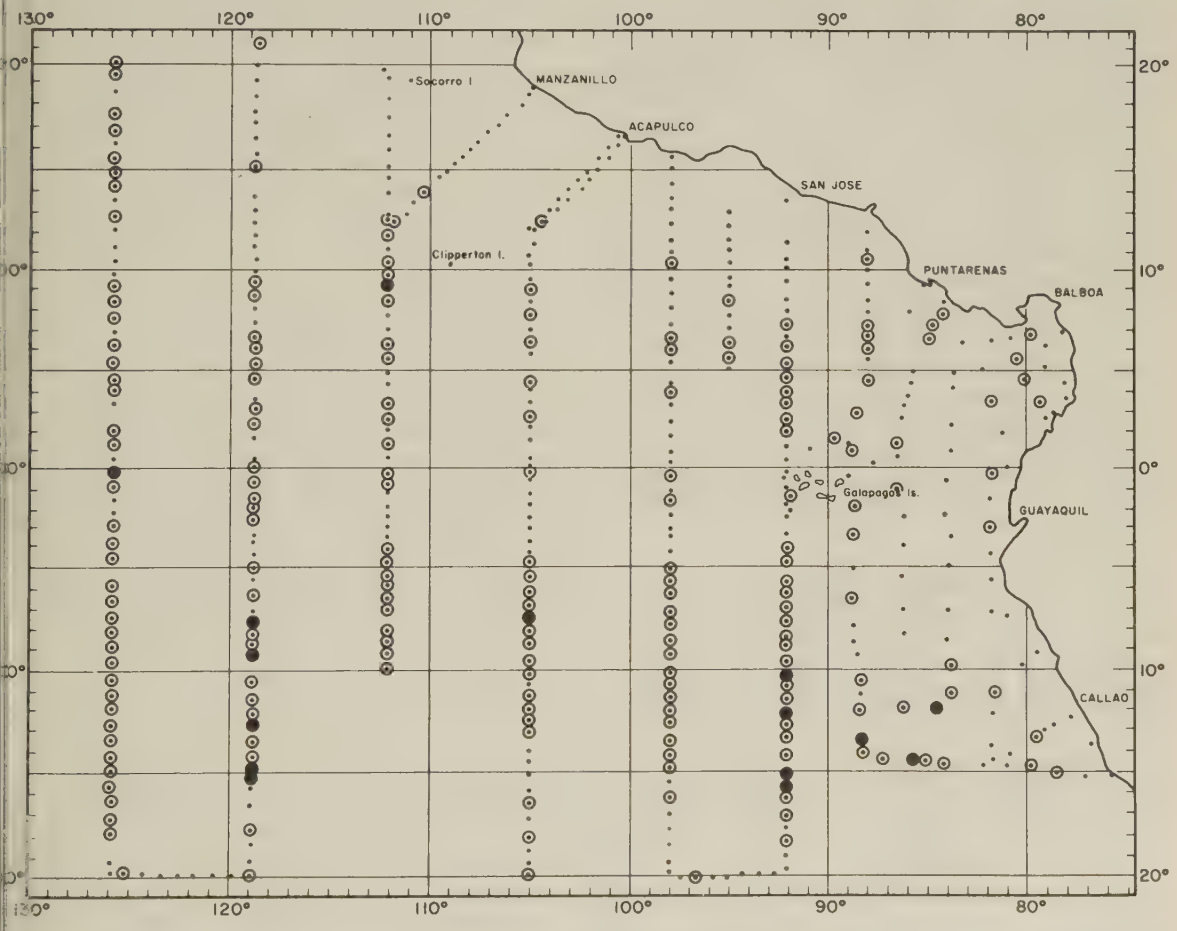


FIGURE 12.—Distribution of larvae of the myctophid, *Symbolophorus evermanni* (Eigenmann and Eigenmann) on EASTROPAC I. Collections of 1 to 25 larvae are shown as large circles with dot in center, collections of 26 or more larvae as large solid circles; negative hauls are shown as small solid circles.

TABLE 16.—Areal occurrence and relative abundance of larvae of Paralepididae on EASTROPAC I.

Latitude	*Argo* 11.000 series		*David Starr Jordan* 12.000 series		*Rockaway* 13.000 series		*Alaminos* 14.000 series		Total EASTROPAC I		
	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	Average no. larvae per positive haul
20° N-15° N	7	9	15	63	4	19	--	--	26	91	3.5
15° N-10° N	3	6	22	105	14	77	--	--	39	188	4.8
10° N- 5° N	10	38	10	25	8	39	8	21	36	123	3.4
5° N- 0°	12	83	15	100	11	145	21	219	59	547	9.3
0° - 5° S	8	22	18	217	14	136	11	72	51	447	8.8
5° S-10° S	8	36	7	17	8	62	2	11	25	126	5.0
10° S-15° S	13	32	6	24	9	20	2	2	30	78	2.6
15° S-20° S	6	16	4	7	14	25	--	--	24	48	2.0
Total	67	242	97	558	82	523	44	325	290	1,648	5.7

separately tabulated in Appendix Table 3: *Macroparalepis macrurus* Ege (35 occurrences, 44 larvae), and *Sudis atrox* Rofen (13 occurrences, 15 larvae). These two species have such characteristic larvae that they are readily identifiable. The larvae of *Macroparalepis macrurus* were widely distributed in the EASTROPAC area, except in the inner pattern occupied by *Alaminos* (Fig. 7). In contrast, the larvae of *Sudis atrox* were confined to the central water mass of the South Pacific (Fig. 7). This species was originally described from the central water mass of the North Pacific (Rofen, 1963; see also Berry and Perkins, 1966). Preliminary study of the other paralepidid material indicated that a number of species were represented, but that the most common larva was the form illustrated by Ege (1953, Fig. 27), simply as "*Lestidium* spec."

15. EVERMANNELLIDAE
(27 occurrences, 38 larvae)

The larvae of Evermannellidae in the EASTROPAC area have not yet been worked out in detail. Three species of Evermannellidae are known to occur: *Coccorella atrata* (Alcock), *Evermannella indica* Brauer, and a form with a higher anal fin count than is found in these two species. The identity of the latter, known only as yet from larval specimens, remains uncertain. Although larvae of Evermannellidae were not common, the occurrences were distributed over much of the EASTROPAC pattern, except nearshore.

16. SCOPELARCHIDAE
(142 occurrences, 329 larvae)

Scopelarchids are widely distributed in the eastern tropical Pacific, usually occurring in small numbers, i.e., one to three larvae per haul. Only 15 % of the positive hauls contained larger numbers of larvae, i.e. 4 to 20 larvae per haul. Scopelarchid larvae were most common between lat 10° and 20° N, as is shown in Table 17.

There are at least five species of scopelarchids represented by the larvae, and perhaps six. I have not attempted to attach specific names to most of the kinds because the adult scopelarchids

TABLE 17.—Areal occurrence and relative abundance of larvae of Scopelarchidae on EASTROPAC I.

Latitude	*Argo* 11.000 series		*David Starr Jordan* 12.000 series		*Rockaway* 13.000 series		*Alaminos* 14.000 series		Total EASTROPAC I		
	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	Average no. larvae per positive haul
20° N-10° N	16	38	25	67	15	84	--	--	56	189	3.4
10° N- 0°	4	4	7	12	10	14	13	27	34	57	1.7
0° -10° S	11	15	9	18	5	8	4	6	29	47	1.6
10° S-20° S	4	7	5	7	9	14	5	8	23	36	1.6
Total	35	64	46	104	39	120	22	41	142	329	2.3

f the eastern tropical Pacific are as yet inadquately known. Most larvae taken between lat 0° and 20° N were those of *Scopelarchoides icholsi* Parr.

17. SCOPELOSAURIDAE
(9 occurrences, 16 larvae)

Two kinds of *Scopelosaurus* larvae were collected in the EASTROPAC area, but neither has been linked to its adult stages as yet; one of these occurred in only a single collection. Most of the specimens of the other form were taken in an equatorial band, between lat 5° N and 5° S.

20. EEL LEPTOCEPHALI
(87 occurrences, 179 larvae in 1.0-m oblique net hauls; 58 occurrences, 553 larvae in 5.0-ft micronekton net hauls)

A total of 10 families of true eels of the order Anguilliformes, suborder Anguilloidei, is represented in the EASTROPAC I collections. Eel leptocephali were decidedly more common in collections made with the 5-ft micronekton net than in the 1-m net collections: 9.5 larvae per positive haul as compared with 2.1 larvae. This difference probably was due in large part to the larger volume of water strained in taking micronekton net hauls, but the faster towing speed of these hauls, ca. 5 knots as compared with 1.5 to 2 knots for 1-m net hauls, also may have contributed. In the discussion of eel families that follows, I have utilized information on occurrence of eel leptocephali from the collections of both nets.

ongridae

Leptocephali of congrid eels were taken at more stations, 57, than those of any other family, yet no congrid larvae were obtained to the south of lat 6° S. Most congrid leptocephali could be identified to genus, of which five were represented; some larvae, however, could not be identified below the family level. Leptocephali of *Ariosoma* were widely distributed between lat 20° N and 3° S, occurring at 28 stations between the coast and the outer line occupied by *Argo*. Leptocephali of *Hildebrandia* were restricted to a broad coastal band, but leptocephali of *Bathyconger* and *Paraconger* were almost as widespread as those of *Ariosoma*. Only one record was obtained of *Gnathopis*.

Derichthyidae

The only definite record is a metamorphosing specimen obtained at station 11.167.

Moringuidae

Leptocephali of *Neoconger* were taken at five coastal stations between lat 8° N and 1° S.

Muraenesocidae

Leptocephali were taken at four stations in the inner pattern occupied by the *Alaminos*, all within 3° of the equator.

Muraenidae

Muraenid leptocephali were taken at 17 stations; two were on the line of stations occupied off Acapulco, Mexico, and the remainder in the broad corridor between Puntarenas, the Galápagos Islands, and the coast of Ecuador.

Nemichthyidae

Two genera of nemichthyid larvae were represented in the EASTROPAC area, *Nemichthys* and *Borodinula*. A specimen of *Nemichthys*, 310 mm long, was obtained at station 14.188. Leptocephali of this family were taken at 24 stations scattered throughout the EASTROPAC area, including the South Pacific central water mass.

Nettastomidae

Taken at 17 stations in the inner half of the EASTROPAC pattern between lat 9° N and 2° S; two kinds of nettastomid larvae were obtained,

one of which was represented by a single specimen.

Ophichthidae

The 31 occurrences of ophichthid eels were distributed in a broad coastal band between Manzanillo, Mexico, and northern Peru (lat 7° S).

Serrivomeridae

Leptocephali of this family were taken at 33 stations, of which 21 were in the outer pattern occupied by *Argo*. Occurrences were grouped into two broad bands—one centered on lat 5° N, the other located between lat 7° and 20° S in the South Pacific central water mass.

Xenocongridae

The leptocephalus of *Chlopsis* was obtained at 22 stations, most located between Panama Bay and the Galápagos Islands.

21. MELAMPHAIDAE
(298 occurrences, 857 larvae)

Melamphaid fishes are the most important family of berycoid fishes in the mesopelagic zone. Four of the five recognized genera occur in the EASTROPAC area: *Melamphaes, Scopelogadus, Scopelobryx,* and *Poromitra.* According to Ebeling (1962) five species of *Melamphaes* are common in the eastern tropical Pacific, two additional species were collected within the EASTROPAC area, and four other species were collected on the fringes of the area. Only one kind of *Scopelogadus, S. mizolepis bispinosus* (Gilbert), is known from the eastern Pacific (Ebeling and Weed, 1963). The remaining two genera, *Scopeloberyx* and *Poromitra,* await revision; the species composition of these genera in the EASTROPAC area is inadequately known. Although melamphaid larvae can be identified to the generic level with some assurance, few developmental series have been worked out at the species level.

Larvae of Melamphaidae were widely distributed in the EASTROPAC area, occurring in 62 % of the collections. Although negative hauls were fewest between the equator and lat 15° N, the average number of larvae per positive haul was rather similar in all areas (Table 18).

23. BREGMACEROTIDAE
(194 occurrences, 1,805 larvae)

Larvae of the gadoid family, Bregmacerotidae, ranked sixth in abundance, contributing 1.9 % of the fish larvae of EASTROPAC I. The only genus, *Bregmaceros,* is widely distributed in pelagic waters of the tropical and subtropical regions of all oceans. D'Ancona and Cavinato (1965) recognized seven species in a worldwide treatment of the genus. These authors stressed the difficulties in species identification.

A preliminary study of EASTROPAC collections of *Bregmaceros* larvae, supplemented by collections of juveniles and adults obtained

TABLE 18.—Areal occurrence and relative abundance of larvae of Melamphaidae on EASTROPAC I.

Latitude	*Argo* 11.000 series		*David Starr Jordan* 12.000 series		*Rockaway* 13.000 series		*Alaminos* 14.000 series		Total EASTROPAC I		
	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	Average no. larvae per positive haul
20°N-15°N	7	17	15	41	3	5	--	--	25	63	2.5
15° N-10° N	13	36	19	41	18	48	--	--	50	125	2.5
10° N- 5° N	14	59	11	26	24	104	9	24	58	213	3.7
5° N- 0°	7	12	11	19	11	36	24	100	53	167	3.2
0° - 5° S	8	12	9	17	11	56	10	41	38	126	3.3
5° S-10° S	9	18	8	17	9	27	10	21	36	83	2.3
10° S-15° S	6	8	2	6	11	29	6	14	25	57	2.3
15° S-20° S	2	3	2	4	9	16	--	--	13	23	1.7
Total	66	165	77	171	96	321	59	200	298	857	2.9

n micronekton hauls, has shown the presence f five kinds. Larvae of *B. bathymaster* Jordan nd Bollman had the most limited distribution, eing a coastal species, but were taken in the argest numbers. Two species occurred in the entral water mass of the South Pacific (*B. aponicus* Tanaka, and perhaps *B. macclellandi* Thompson). Another species occurred in the quatorial current system, and a fifth species vas widely distributed between lat 7° and 20° N. One or both of the latter may be undescribed.

26. EXOCOETIDAE
(78 occurrences, 189 larvae)

The species composition of flyingfish larvae as not been worked out in detail as yet. Only arvae of the most common species, *Oxyporamphus micropterus* (Cuvier and Valenciennes) (51 occurrences, 121 larvae) have been separately tabulated (Appendix Table 3). Larvae f *Oxyporhamphus* were taken at a number of tations in a coastal band off Mexico and central America. Offshore occurrences were limited o an equatorial band between lat 5° S and 7° N. Only one occurrence of larvae of this species vas obtained to the south of lat 5° S. Exocoetid larvae undoubtedly are undersampled in oblique plankton hauls, both because of their hallow depth distribution and their marked swimming ability. Much more material of exocoetids—eggs, larvae, and juveniles—are present in surface plankton hauls; only a few of hese have been sorted as yet from EASTRO-PAC I.

28. GEMPYLIDAE-TRICHIURIDAE
(103 occurrences, 231 larvae)

The larvae of these two families are grouped together for reasons discussed below. Larvae of four species of gempylids-trichiurids appear to be widely distributed in the eastern Pacific: these are *Nealotus tripes* Johnson (42 occurrences, 82 larvae, Fig. 7), *Gempylus serpens* Cuvier and Valenciennes (40 occurrences, 57 larvae, Fig. 13), *Diplospinus multistriatus* Maul (26 occurrences, 62 larvae, Fig. 14), and *Lepidopus* sp. (7 occurrences, 25 larvae, Fig. 14). Records of the occurrence of these in EASTROPAC hauls also are given in Appendix Table 5, and summarized in Table 19. One or two specimens each were taken of larvae of two or three additional species of gempylids-trichiurids.

Late larval stages already have been described for three of the above species (Voss, 1954; Strasburg, 1964), but early developmental stages have not been described, except for a species of *Lepidopus*. We plan to describe the early stage larvae of all the above species.

The larval series of these four species raise questions about the distribution of genera between these two families, and perhaps, about the need for two families. Larvae of *Diplospinus multistriatus* are quite similar to those of *Gempylus serpens*. This similarity is marked enough to have led Voss (1954) to describe the larvae of *Diplospinus* as those of *Gempylus* (*i.e.* her *Gempylus* A). Her *Gempulus* B larvae are those of *Gempylus serpens*.

TABLE 19.—Summary of occurrences and relative abundance of species of Gempylidae-Trichiuridae in the four vessel patterns occupied on EASTROPAC I.

Species	*Argo* 11.000 series		*David Starr Jordan* 12.000 series		*Rockaway* 13.000 series		*Alaminos* 14.000 series		Total EASTROPAC I	
	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae
Nealotus tripes	6	6	2	7	12	34	22	35	42	82
Gempylus serpens	8	10	15	19	11	18	6	10	40	57
Diplospinus multistriatus	5	10	0	0	9	31	12	21	26	62
Lepidopus sp. *(xantusi)*	0	0	0	0	1	17	6	8	7	25
Other	0	0	2	2	2	3	0	0	4	5
Total	19	26	18	28	31	103	35	74	103	231

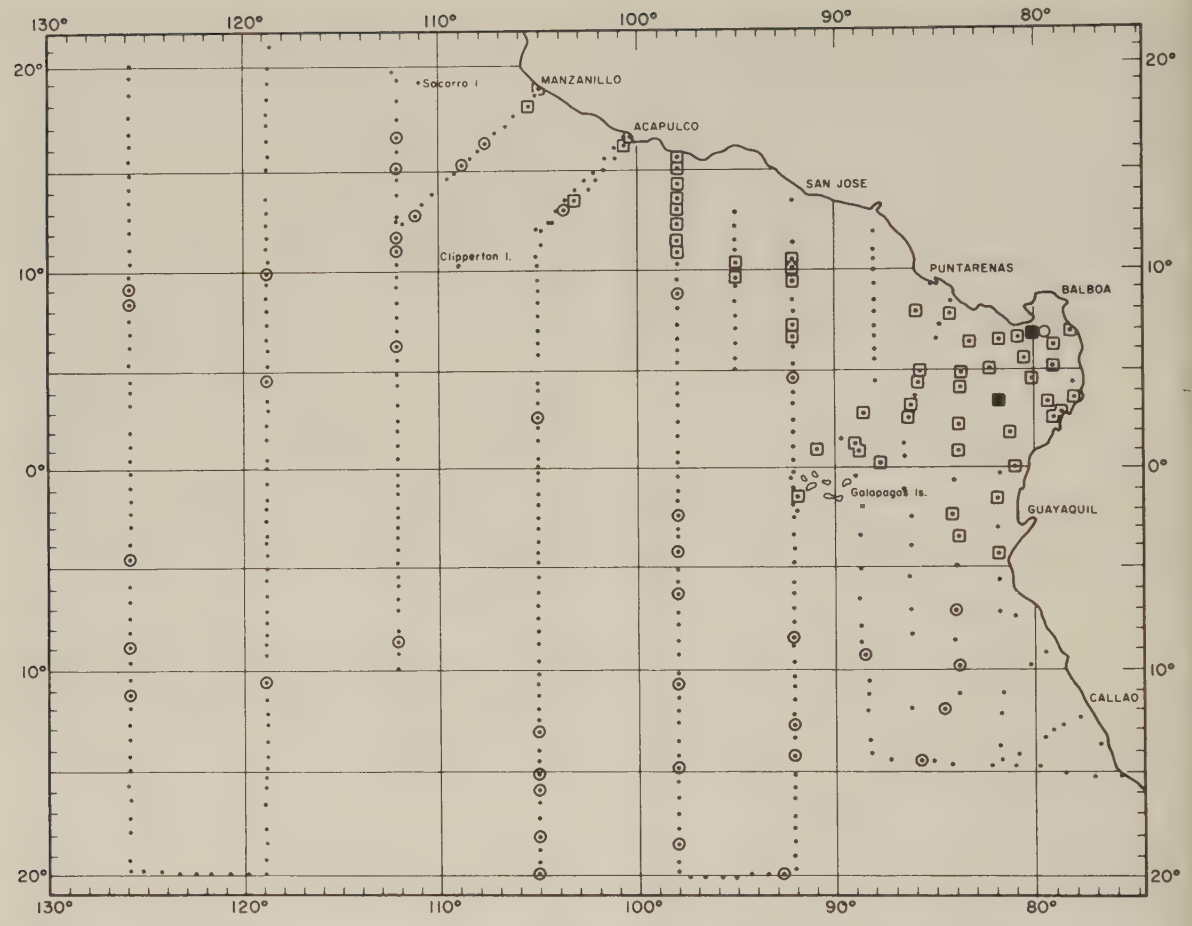


FIGURE 13.—Distribution of larvae of the gempylid, *Gempylus serpens* Cuvier and Valenciennes, and of the cynoglossid flatfish, *Symphurus* spp., on EASTROPAC I. Records of occurrence of larvae of *G. serpens* are shown as large circles with dot in center, *Symphurus* spp. as open squares for hauls containing 1 to 25 larvae and solid squares for hauls with 26 or more larvae; negative hauls are shown as small solid circles.

29. SCOMBRIDAE
(185 occurrences, 1,919 larvae)

Larvae of scombrid fishes ranked fifth in abundance, and made up over 2 % of the larvae. Larvae of the bullet mackerel, *Auxis* spp., (161 occurrences, 1,563 larvae) were by far the most abundant and widely distributed. Larvae of skipjack tuna, *Katsuwonus pelamis* (Linnaeus) (17 occurrences, 214 larvae) were taken mostly in the offshore southern portion of the EASTROPAC area. Other scombrid larvae included yellowfin tuna, *Thunnus albacares* (Bonnaterre) (19 occurrences, 40 larvae); bigeye tuna, *Thunnus obesus* Lowe (1 occurrence, 1 larva); black skipjack, *Euthynnus lineatus* Kishinouye (2 occurrences, 77 larvae); regular *Scomber* sp. (2 occurrences, 7 larvae); Spanish mackerel, *Scomberomorus* sp. (2 occurrences, 3 larvae); and the wahoo, *Acanthocybium solandri* (Cuvier) (1 occurrence, 1 larva). The tuna larvae have been turned over to W. Klawe of the Inter-American Tropical Tuna Commission for detailed study. He kindly has given me permission to include data on occurrence and abundance of larvae of skipjack and bullet mackerel in Ap-

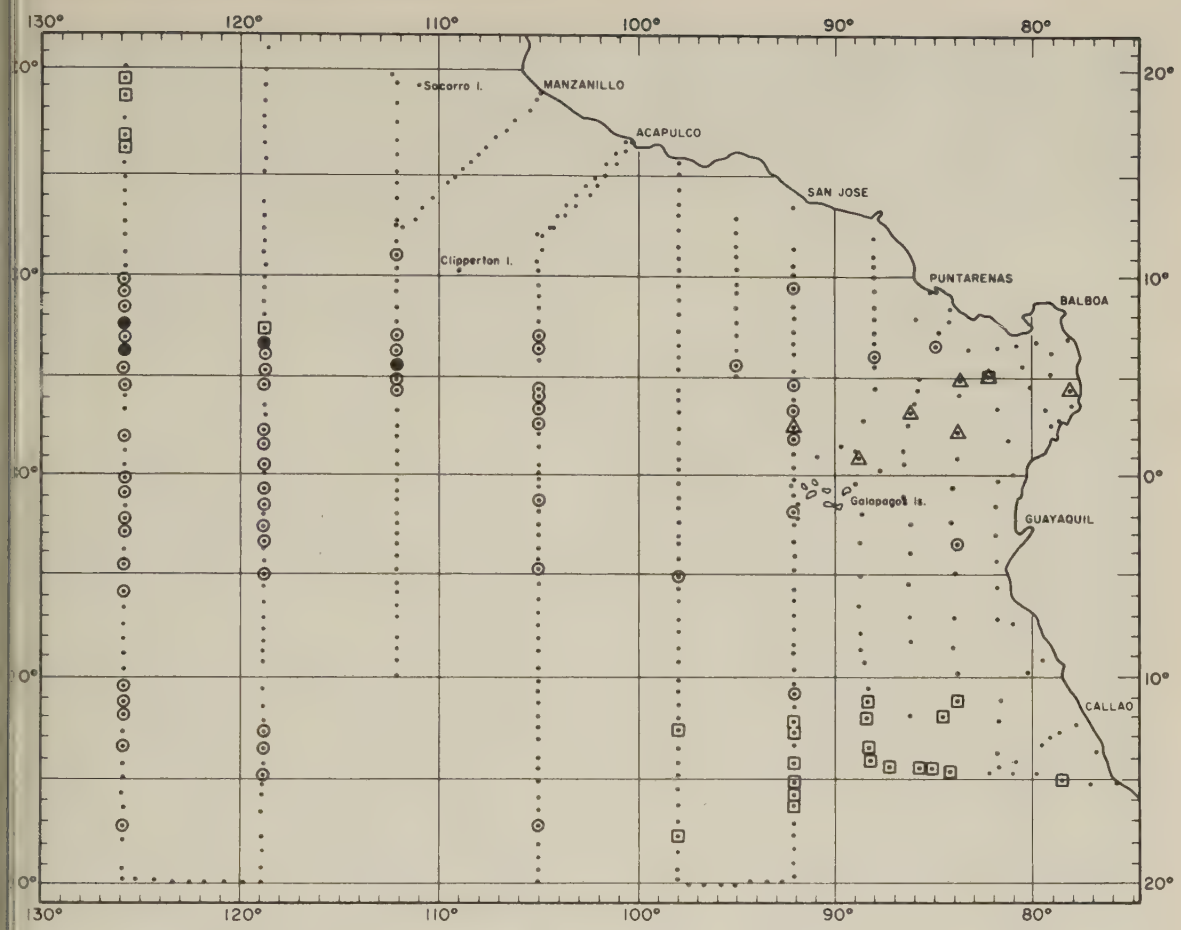


FIGURE 14.—Distribution of larvae of the apogonid, *Howella pammelas* (Heller and Snodgrass), and of the trichiurids, *Diplospinus multistriatus* Maul and *Lepidopus* sp. Records of occurrence of larvae of *H. pammelas* are shown as large circles with dot in center for hauls containing 1 to 10 larvae and large solid circles for hauls containing 11 or more larvae; records of occurrence of larvae of *D. multistriatus* are shown as squares, *Lepidopus* sp. are triangles; negative hauls are shown as small solid circles.

endix Table 3. Charts showing distribution nd relative abundance of larvae of *Auxis* sp. nd of *Katsuwonus pelamis* on EASTROPAC ruises will be included in the EASTROPAC tlas.

30. ISTIOPHORIDAE
(2 occurrences, 2 larvae)

The striking larvae of istiophorids are readily dentified to family. The marked paucity of larvae of marlin and sailfish in EASTROPAC I collections was unanticipated, inasmuch as adult billfish are an important part of the Japanese longline catches from the tropical eastern Pacific (Kume and Schaefer, 1966).

32. APOGONIDAE
(61 occurrences, 204 larvae)

Most species of apogonids are coastal, shallow-water forms. A few larvae of these were

taken on EASTROPAC I. However, the majority of apogonid larvae were those of *Howella pammelas* (Heller and Snodgrass), a pelagic species that occurred most commonly in the offshore pattern occupied by *Argo* (Fig. 14). An excellent developmental series has been obtained of this species.

36. CARANGIDAE
(31 occurrences, 183 larvae)

Although a number of kinds of carangid larvae were obtained on EASTROPAC I only larvae of the pilotfish, *Naucrates ductor* (L.), are separately tabulated (Appendix Table 3). Most carangid larvae were taken at stations adjacent to the coast or in the vicinity of offshore islands or banks, and over 50 % of the carangid larvae were obtained at two stations (13.019-70 larvae, 14.016-34 larvae). In these larger collections, the most common carangid larvae were *Chloroscombrus orqueta* Jordan and Gilbert and *Selene brevoorti* (Gill). Several times as many young carangids were taken in one haul of the 5-ft micronekton net as in all plankton samples: 384 specimens at station 14.014. Species composition was as follows: *Naucrates ductor*, 288 specimens, 13.0 to 27.5 mm; *Elagatis bipinnulatus* Quoy and Gaimard, 71 specimens, 18.5 to 42.0 mm; and *Caranx caballus* Günther, 25 specimens, 12.0 to 25.0 mm.

40. CORYPHAENIDAE
(86 occurrences, 118 larvae)

Larvae of the dolphin, *Coryphaena* spp., were widely distributed throughout the EASTROPAC area, but occurred in small numbers, usually one or two specimens per positive haul (average 1.4). The occurrence and abundance of *Coryphaena* larvae in various parts of the EASTROPAC area are summarized in Table 20. The majority of specimens obtained were early-stage larvae; no attempt was made to distinguish between the two species of *Coryphaena*. Charts showing distribution of *Coryphaena* larvae on EASTROPAC cruises will be included in the EASTROPAC Atlas.

44. NOMEIDAE
(178 occurrences, 961 specimens)

The nomeids are an important constituent of the epipelagic fauna of the open ocean. Two genera were represented in the EASTROPAC collections, *Psenes* and *Cubiceps*. Larvae of *Cubiceps* were the more common, but more kinds of *Psenes* larvae were obtained. Altogether, eight different kinds of nomeid larvae have been observed, which differ in meristics, pigmentation, and body shape. In several developmental series of larvae of the genus *Psenes* the pelvic fins developed early, and became conspicuously long and pigmented on older larvae. The larger collections of nomeid larvae were obtained between lat 10° N and 5° S (Fig. 15). Only a few collections were obtained to the south of lat 7° S in the patterns occupied by the *Argo*, *Jordan*, and *Rockaway*, i.e. in the central water mass of the South Pacific. Areal occurrences and relative abundance of nomeid larvae on EASTROPAC I are summarized in Table 21.

TABLE 20.—Areal occurrence and relative abundance of larvae of *Coryphaena* spp. on EASTROPAC I.

Latitude	*Argo* 11.000 series		*David Starr Jordan* 12.000 series		*Rockaway* 13.000 series		*Alaminos* 14.000 series		Total EASTROPAC I		
	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	Average no. larvae per positive haul
20° N-10° N	3	4	7	9	6	6	--	--	16	19	1.2
10° N- 0°	14	17	9	17	6	6	9	13	38	53	1.4
0° -10° S	5	6	6	9	4	10	5	7	20	32	1.6
10° S-20° S	2	2	1	1	3	3	6	8	12	14	1.2
Total	24	29	23	36	19	25	20	28	86	118	1.4

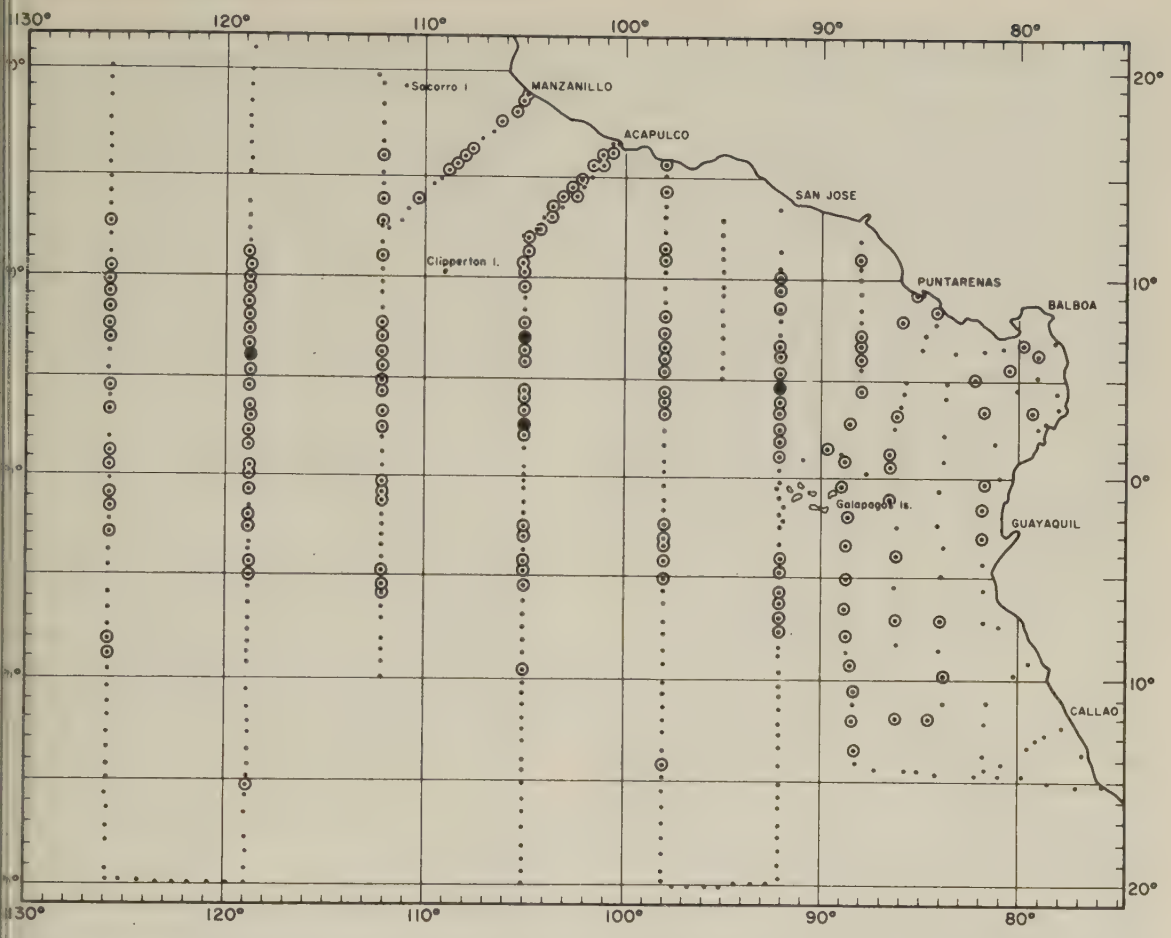


FIGURE 15.—Distribution of larvae of the family Nomeidae on EASTROPAC I. Collections of 1 to 25 larvae are shown as large circles with dot in center, of 26 or more larvae as large solid circles; negative hauls are shown as small solid circles.

TABLE 21.—Areal occurrence and relative abundance of larvae of Nomeidae on EASTROPAC I.

Latitude	*Argo* 11.000 series		*David Starr Jordan* 12.000 series		*Rockaway* 13.000 series		*Alaminos* 14.000 series		Total EASTROPAC I		
	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	Average no. larvae per positive haul
20° N-15° N	0	0	11	39	3	7	--	--	14	46	3.3
15° N-10° N	5	12	11	24	10	26	--	--	26	62	2.4
10° N- 5° N	12	81	9	87	17	87	7	21	45	276	6.1
5° N- 0°	11	46	9	130	9	76	9	39	38	291	7.7
0° - 5° S	8	26	8	60	6	78	8	30	30	194	6.5
5° S-10° S	2	3	4	6	5	16	7	44	18	69	3.8
10° S-15° S	0	0	0	0	1	1	5	12	6	13	2.2
15° S-20° S	1	10	0	0	0	0	--	--	1	10	10.0
Total	39	178	52	346	51	291	36	146	178	961	5.4

51. TETRAGONURIDAE
(6 occurrences, 7 specimens)

Only a few specimens of *Tetragonurus* larvae were obtained in EASTROPAC I collections. Larvae of *Tetragonurus* have been taken rather commonly in the California Current region and were an important constituent in NORPAC collections. These interesting oceanic fishes were revised by Grey (1955), who recognized three species. Two of these were present in the EASTROPAC area: *T. atlanticus* Lowe and *T. cuvieri* Risso. Late-stage larvae of the two species can be separated by differences in their meristics, and also by differences in pigmentation and body form; larvae of *T. atlanticus* are more heavily and uniformly pigmented and are deeper bodied than larvae of *T. cuvieri* (Grey, 1955).

PLEURONECTIFORMES
(79 occurrences, 503 larvae)

Larvae of flatfishes (Pleuronectiformes) in EASTROPAC collections belonged only to the families Bothidae and Cynoglossidae. Information concerning the kinds and numbers of flatfish larvae taken at each of 79 EASTROPAC I stations is contained in Appendix Table 6; this information is summarized in Table 22.

Flatfish larvae were taken in a broad coastal band, several hundred miles wide, between Manzanillo, Mexico, and northern Peru. The occurrences of some kinds of flatfish larvae and juveniles at considerable distances from shore have been commented upon by a number of workers. Kyle (1913) obtained larvae of *Bothus* from across the North Atlantic and larvae of *Syacium* at considerable distances from shore. Bruun (1937a, 1937b) described bathypelagic occurrences of the bothid flatfish, *Chascanopsetta* and *Monolene*, the latter from off Panama, and of the pleuronectid flatfish, *Poecilopsetta*. Ahlstrom (1965) illustrated the widespread offshore distribution of larvae of *Citharichthys* spp. in the California Current region.

54. BOTHIDAE
(56 occurrences, 199 larvae)

Several kinds of bothid flatfish larvae were taken in 20 or more collections, including larvae of *Bothus leopardinus* (Günther), *Syacium ovale*, and *Citharichthys-Etropus*. Some interesting forms taken less frequently included larvae of *Cyclopsetta* sp., *Engyophrys sancti-laurentii* Jordan and Bollman, and of *Monolene*. A short section will be devoted to each of the above.

Bothus leopardinus (Günther) (28 occurrences, 50 larvae)

Although Norman (1934) lists three species of *Bothus* as occurring in the eastern tropical Pacific—*Bothus mancus* (Broussonet), *B. leop-*

TABLE 22.—Frequency of occurrence and relative abundance of the principal kinds of flatfish larvae, Pleuronectiformes, on EASTROPAC I, summarized by vessel pattern.

Flatfish larvae	*Argo* 11.000 series		*David Starr Jordan* 12.000 series		*Rockaway* 13.000 series		*Alamitos* 14.000 series		Total EASTROPAC I	
	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae	No. positive hauls	No. larvae
BOTHIDAE										
Bothus leopardinus	0	0	1	4	15	32	12	14	28	50
Citharichthys-Etropus	0	0	2	2	6	8	18	40	26	50
Cyclopsetta sp.	0	0	0	0	2	2	1	2	3	4
Engyophrys sancti-laurentii	0	0	0	0	2	3	6	6	8	9
Syacium ovale	0	0	2	8	13	60	9	16	24	84
Other Bothidae	0	0	0	0	1	1	1	1	2	2
Total Bothidae	0	0	3	14	24	106	29	79	56	199
CYNOGLOSSIDAE										
Symphurus spp.	0	0	5	17	21	102	37	185	63	304
Total Pleuronectiformes	0	0	6	31	30	208	43	264	79	503

rdinus (Günther), and *B. constellatus* (Jor-an)—he notes that the latter is very doubtfully stinct from *B. leopardinus.* Based on larval aterial, there appears to be only one common, idely distributed species in the eastern Pacific Fig. 10), which is referred to *B. leopardinus.* lacks pigmentation, except for a dorsal and entral finfold spot near the end of the noto-ord. This finfold pigment has been observed a number of species of *Bothus,* hence may e a generic character. *Bothus* larvae are read-y separable from other bothid flatfish larvae the EASTROPAC area by a number of char-teristics. Young-stage larvae possess a single ongated anterior dorsal ray, which becomes in-nspicuous in older larvae. Older larvae are ery deep bodied, usually lack pigmentation and ck head spination. The pelvic fin base on the ft side originates mostly anterior to the cleith-m, not posterior as in *Syacium, Engyophrys, yclopsetta,* or *Citharichthys,* and the fin on e ventral midline is much broader based than these genera. Almost 100 specimens of *othus* larvae from the tropical eastern Pacific ave been cleared and stained (based in part EASTROPAC material, in part on previous xpeditions). The modal number of vertebrae as 10 + 28 = 38.

Several specimens of flatfish larvae were taken EASTROPAC I, and on previous expeditions, at had an exceptionally heavy, elongated, ngle anterior dorsal ray, such as have been escribed for several genera of bothid flatfish the subfamily Bothinae. However, the pelvic ns formed behind the cleithrum and the fin the ventral margin was not much wider ased than its recessed partner. These intrigu-g larvae appear to be those of *Monolene.* wo different kinds have been obtained from the stern tropical Pacific, one form has 10 + 35 rtebrae, the other has 10 +28 vertebrae. The tter may be the larva of *Monolene asaedai* erkins, 1963).

yclopsetta sp. (3 occurrences, 4 specimens)

Larvae of *Cyclopsetta* are more closely re-ted to those of *Syacium* than to other bothid genera. Larvae of both genera develop marked opercular spination as well as a sphenotic spine on either side of the head. *Cyclopsetta* larvae develop 8 to 11 elongated anterior dorsal rays, rather than 5 to 8 as in *Syacium. Cyclopsetta* larvae also attain a larger size before transformation; larval specimens as large as 32 mm have been observed in the EASTROPAC area. In late-stage larvae of *Cyclopsetta* the anterior group of dorsal rays is quite elongated, but a more striking feature is the marked development of three rays of the left pelvic fin which may extend almost to the base of the caudal fin. The *Cyclopsetta* larvae have a larger number of vertebrae—usually 10 + 29, as compared to 10 + 25 for larvae of *Syacium ovale* (Günther). Three species of *Cyclopsetta* have been described from the tropical eastern Pacific—*C. querna* (Jordan and Bollman), *C. panamensis* (Steindachner), and *C. maculifera* (Garman), but only *C. querna* has been collected with any frequency as juveniles and adults. The usual count of vertebrae in *C. querna* and *C. panamensis* is 10 + 29; the vertebral count of *C. maculifera* is not known.

Engyrophrys sancti-laurentii Jordan and Bollman (8 occurrences, 9 larvae)

Larvae of *Engyophrys* are about as deep bodied as those of *Bothus.* They possess heavy serrations on the ventral edge of the body both fore and aft of the cleithrum; three small spines also develop on the otic region of the head. The pelvic fins develop immediately posterior to the cleithrum and anterior to the posterior group of ventral serrations. A cleared and stained specimen, 18 mm long, from station 13.040 had 10 + 31 vertebrae, 86 dorsal rays, 71 anal rays, and 17 caudal rays.

Syacium ovale (Günther) (24 occurrences, 84 larvae)

A larval stage of *Syacium* was first illustrated by Kyle (1913) as "*Ancylopsetta* sp." *Syacium* has a distinctive larva with heavy opercular spination, a sphenotic spine on either side of

the head, and 5 to 8 elongated anterior dorsal rays. Larvae of the closely related genus, *Cyclopsetta,* also develop opercular and head spination. The opercular spination is more pronounced in *Syacium*—particularly an antlerlike spine that develops on the posterior border of the preoperculum. The three anterior rays of the left pelvic fin become only moderately elongated in *Syacium* larvae; the rays are of about equal length, firmly joined together by a membrane, and pigmented distally. The full complement of dorsal and anal fin rays usually are laid down before the larvae attain a standard length of 10 mm; the largest specimens studied, ca. 20 mm long, were undergoing metamorphosis.

Citharichthys-Etropus (26 occurrences, 50 larvae)

Before discussing problems in identification of *Citharichthys-Etropus* larvae from the EASTROPAC area, some background information will be given on *Citharichthys* larvae in the CalCOFI region. Illustrations of larvae of three species of *Citharichthys* were given in Ahlstrom (1965). Two species, *Citharichthys sordidus* (Girard) and *C. xanthostigma* Gilbert, develop 2 elongated dorsal rays and also 2 elongated ventral rays on larvae larger than about 5 mm; the other species never develops such rays. Another species that occurs off central and southern Baja California, *C. fragilis* Gilbert, also develops 2 elongated rays on the dorsal and ventral fins.

Two species of *Citharichthys, C. gilberti* Jenkins and Evermann, and *C. platophrys* Gilbert, and the widely distributed *Etropus crossotus* Jordan and Gilbert are known to occur in the EASTROPAC area. Three kinds of larvae were taken in EASTROPAC collections referable to *Citharichthys* or *Etropus.* The most common kind developed 3 elongated dorsal rays, a less common form developed 2 elongated dorsal rays, and some specimens lacked elongated rays. The form with 3 elongated dorsal rays is almost certainly referable to *Citharichthys.* Larvae of a common Atlantic species, *C. arctifrons* Goode, develop 3 elongated dorsal rays, confirming the presence of this combination in *Citharichthys* larvae. A cleared and stained specimen from station 13.040 with 3 elongated dorsal rays possessed 10 + 25 vertebrae, 78 dorsal rays, and 59 anal rays. The meristics of the dorsal and anal fins could fit either *C. platophrys* or *C. gilberti.* Yet so little is known of *C. platophrys* that I would hesitate to refer the common *Citharichthys* larvae in EASTROPAC material to this species. A similar problem attends larvae of the form that lacks elongated dorsal rays. Two specimens, 11.5 and 12.0 mm, from station 14.014 each had 88 dorsal and 67 anal rays; vertebrae counts were 10 + 23 and 10 + 24. These counts best fit *E. crossotus,* except that the vertebral counts are low. No material of the form with 2 dorsal rays (undoubtedly a *Citharichthys*) has been cleared and stained for precise meristics. A definite identification has yet to be made on all three kinds of larvae.

55. CYNOGLOSSIDAE
(63 occurrences, 304 larvae)

Only one cynoglossid genus, *Symphurus,* occurs in the eastern Pacific. Five or more kinds of *Symphurus* larvae were obtained in EASTROPAC collections; these were obtained in more collections than larvae of bothid flatfishes (63 as compared with 56), and made up a larger percentage of the total flatfish larvae (ca. 60 %). A moderate number of recently transformed specimens of *Symphurus* were obtained in EASTROPAC collections; in contrast, all specimens of bothid flatfish were pretransformation larvae. The distribution of *Symphurus* larvae in EASTROPAC I is shown in Figure 13.

ACKNOWLEDGMENTS

I am indebted to a number of persons for assistance during the preparation of this manuscript. Kenneth Raymond prepared the distribution charts. Amelia Gomes helped in many facets of the work including the preparation of cleared and stained specimens of flatfishes and other groups. H. Geoffrey Moser has worked closely in studies of larvae of Myctophidae and Gonostomatidae. W. L. Klawe has been help-

ful in many ways; he graciously has permitted me to include station information on occurrence and numbers of larvae of *Auxis* sp. and skipjack tuna. I wish particularly to thank David Kramer and H. Geoffrey Moser for reviewing the manuscript.

LITERATURE CITED

AHLSTROM, ELBERT H.
1953. Pilchard eggs and larvae and other fish larvae, Pacific Coast - 1951. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 102. 55 p.
1959. Vertical distribution of pelagic fish eggs and larvae off California and Baja California. U.S. Fish Wildl. Serv., Fish. Bull. 60: 107-146.
1965. Kinds and abundance of fishes in the California Current region based on egg and larval surveys. Calif. Coop. Oceanic Fish. Invest. Rep. 10: 31-52.
1969. Mesopelagic and bathypelagic fishes in the California Current region. Calif. Coop. Oceanic Fish. Invest. Rep. 13: 39-44.

AHLSTROM, ELBERT H., AND ROBERT C. COUNTS.
1958. Development and distribution of *Vinciguerria lucetia* and related species in the eastern Pacific. U.S. Fish Wildl. Serv., Fish. Bull. 58: 363-416.

AHLSTROM, ELBERT H., AND H. GEOFFREY MOSER.
1969. A new gonostomatid fish from the tropical eastern Pacific. Copeia 1969(3): 493-500.

ALVERSON, FRANKLIN G.
1961. Daylight surface occurrence of myctophid fishes off the coast of Central America. Pac. Sci. 15(3): 483.

BEEBE, WILLIAM, AND MARY VANDER PYL.
1944. Eastern Pacific expeditions of the New York Zoological Society. XXXIII. Pacific Myctophidae. (Fishes.) Zoologica (New York) 29(2): 59-95.

BERRY, FREDERICK H., AND HERBERT C. PERKINS.
1966. Survey of pelagic fishes of the California Current area. U.S. Fish Wildl. Serv., Fish. Bull. 65(3): 625-682.

BRUUN, ANTON FR.
1937a. *Monolene danae*, a new flatfish from Panama, caught bathypelagically. Ann. Mag. Natur. Hist., 10th Ser. 19(110): 311-312.
1937b. *Chascanopsetta* in the Atlantic; a bathypelagic occurrence of a flatfish, with remarks on distribution and development of certain other forms. Vidensk. Medd. Dansk Naturhist. Foren. 101: 125-136.

BUSSING, WILLIAM A.
1965. Studies of the midwater fishes of the Peru-Chile Trench. *In* George A. Llano (editor), Biology of the Antarctica Seas II, p. 185-227. Antarctic Res. Ser. 6. Nat. Acad. Sci. Nat. Res. Counc. Publ. 1297.

D'ANCONA, UMBERTO, AND GEMINIANO CAVINATO
1965. The fishes of the family Bregmacerotidae. Dana Rep. Carlsberg Found. 64, 92 p.

EBELING, ALFRED W.
1962. Melamphaidae I. Systematics and zoogeography of the species in the bathypelagic fish genus *Melamphaes* Günther. Dana Rep. Carlsberg Found. 58, 164 p.

EBELING, ALFRED W., AND WALTER H. WEED III.
1963. Melamphaidae III. Systematics and distribution of the species in the bathypelagic fish genus *Scopelogadus* Vaillant. Dana Rep. Carlsberg Found. 60, 58 p.

EGE, VILH.
1953. Paralepididae I (*Paralepis* and *Lestidium*). Dana Rep. Carlsberg Found. 40, 184 p.

FRASER-BRUNNER, A.
1949. A classification of the fishes of the family Myctophidae. Proc. Zool. Soc. London 118(4): 1019-1106.

GARMAN, S.
1899. Reports on an exploration off the west coasts of Mexico, Central and South America, and off the Galapagos Islands, in charge of Alexander Agassiz, by the U.S. Fish Commission steamer "Albatross," during 1891, Lieut. Commander Z. L. Tanner, U. S. N., commanding. XXVI. The fishes. Mem. Mus. Comp. Zool Harvard Coll. 24, 431 p.

GIBBS, ROBERT H., JR.
1964. Family Idiacanthidae. *In* Fishes of the western North Atlantic, p. 512-522. Mem. Sears Found. Mar. Res. 1, Part 4.
1969. Taxonomy, sexual dimorphism, vertical distribution, and evolutionary zoogeography of the bathypelagic fish genus *Stomias* (Stomiatidae). Smithsonian Contrib. Zool. 31, 25 p.

GREY, MARION.
1955. The fishes of the genus *Tetragonurus* Risso. Dana Rep. Carlsberg Found. 41, 75 p.
1960. A preliminary review of the family Gonostomatidae, with a key to the genera and the description of a new species from the tropical Pacific. Bull. Mus. Comp. Zool. Harvard Coll. 122(2): 55-125.
1961. Fishes killed by the 1950 eruption of Mauna Loa, Part V, Gonostomatidae. Pac. Sci. 15(3): 462-476.
1964. Family Gonostomatidae. *In* Fishes of the western North Atlantic, p. 78-240. Mem. Sears Found. Mar. Res. 1, Part 4.

KUME, SUSUMU, AND MILNER B. SCHAEFER.
1966. Studies on the Japanese long-line fishery for tuna and marlin in the eastern tropical Pacific Ocean during 1963. Inter-Amer. Trop. Tuna Comm. Bull. 11(3): 101-170.

KYLE, H. M.
1913. Flat-fishes (Heterosomata). Rep. Dan. Oceanogr. Exped. 1908-10 Mediter. Adjacent Seas 2(A.1), 150 p.

MOSER, H. GEOFFREY, AND ELBERT H. AHLSTROM.
1970. Development of lanternfishes (family Myctophidae) in the California Current. Part I. Species with narrow-eyed larvae. Bull. Los Angeles County Mus. Natur. Hist., Sci. 7, 145 p.

NAFPAKTITIS, BASIL G., AND MARY NAFPAKTITIS.
1969. Lanternfishes (family Myctophidae) collected during cruises 3 and 6 of the R/V *Anton Bruun* in the Indian Ocean. Bull. Los Angeles County Mus. Natur. Hist., Sci. 5, 79 p.

NORMAN, J. R.
1934. A systematic monograph of the flatfishes (Heterosomata). Vol. 1, Psettodidae, Bothidae, Pleuronectidae. British Museum (Natural History), London. viii + 459 p.

PERKINS, HERBERT C.
1963. Redescription and second known record of the bothid fish, *Monolene asaedai* Clark. Copeia 1963(2): 292-295.

PERTSEVA-OSTROUMOVA, T. A.
1964. Come morphological characteristics of myctophid larvae (Myctophidae, Pisces). [In Russian]. (Transl., 1966, *In* T. S. Rass (editor), Fishes of the Pacific and Indian Oceans, biology and distribution, p. 79-97. (Available Clearinghouse for Federal Scientific and Technical Information, Springfield, Va., as 65-50120.)

ROFEN, ROBERT R.
1963. Diagnoses of new genera and species of alepisauroid fishes of the family Paralepididae. Aquatica 2, 7 p.

RYTHER, JOHN H.
1969. Photosynthesis and fish production in the sea. Science 166(3901): 72-76.

STRASBURG, DONALD W.
1964. Postlarval scombroid fishes of the genera *Acanthocybium, Nealotus,* and *Diplospinus* from the central Pacific Ocean. Pac. Sci. 18(2): 174-185.

TÅNING, A. VEDEL.
1918. Mediterranean Scopelidae (*Saurus, Aulopus, Chlorophthalmus* and *Myctophum*). Rep. Dan. Oceanogr. Exped. 1908-10. Mediter. Adjacent Seas 2(A.7), 154 p.

VOSS, NANCY A.
1954. The postlarval development of the fishes of the family Gempylidae from the Florida Current. I. *Nesiarchus* Johnson and *Gempylus* Cuv. and Val. Bull. Mar. Sci. Gulf Carib. 4(2): 120-159.

APPENDIX TABLE 1.—Counts of fish larvae, tabulated by family, for all stations occupied on EASTROPAC I.

STATION NUMBER	Bathylagidae	Gonostomatidae	Sternoptychidae	Astronesthidae	Chauliodontidae	Idiacanthidae	Other Stomiatoidei	Myctophidae	Paralepididae	Scopelarchidae	Eel leptocephali	Melamphaeidae	Bregmacerotidae	Exocoetidae	Scombridae	Gempylidae-Trichiuridae	Nomeidae	Bramidae	Chiasmodontidae	Other identified larvae	Unidentified larvae	Disintegrated larvae	Total fish larvae
11.022	0	10	1	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
.025	0	52	0	0	0	0	0	11	1	3	0	0	0	0	0	0	0	0	0	0	2	0	69
.027	0	36	0	0	0	4	0	14	1	0	0	0	0	0	0	0	0	0	0	1	0	1	57
.030	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3
.032	1	15	0	0	0	0	0	19	0	0	0	0	2	0	0	0	0	0	0	0	2	1	40
.034	1	88	0	0	0	1	0	35	0	0	0	0	0	0	0	0	0	0	0	0	1	2	128
.036	0	26	0	0	0	0	1	3	1	0	0	0	3	0	0	0	0	0	0	0	0	0	34
.038	4	22	0	0	0	4	0	21	2	0	0	0	6	0	0	0	0	0	0	0	1	0	60
.040	0	20	0	0	0	11	0	55	0	3	0	3	3	0	0	0	0	0	0	4	1	0	100
.044	2	9	0	0	0	20	0	5	1	0	0	2	4	0	0	0	0	0	0	0	3	0	46
.046	3	58	0	0	0	22	0	50	0	4	0	1	2	0	0	0	0	0	1	1	1	3	146
.048	12	41	0	0	0	12	0	20	3	1	0	3	1	0	0	0	0	0	0	0	0	1	94
.050	24	23	0	0	0	3	1	36	0	1	0	2	0	0	0	0	0	0	0	0	1	10	101
.052	15	3	15	0	0	2	0	58	0	0	0	4	2	0	0	0	1	1	0	0	0	1	102
.054	11	8	17	0	0	0	0	159	0	1	0	2	0	0	0	0	3	0	0	0	0	4	205
.056	10	8	0	0	0	0	0	67	0	5	0	0	0	0	0	1	5	0	0	0	5	12	113
.058	10	3	14	0	0	0	0	28	0	0	0	6	2	0	0	0	1	0	0	1	1	10	76
.060	13	9	30	2	1	0	0	72	2	0	0	2	0	0	3	0	5	0	0	2	5	1	147
.062	0	0	6	0	0	0	0	21	2	0	0	5	1	0	0	0	1	0	0	0	1	3	40
.064	0	1	22	0	0	0	2	51	0	0	0	3	3	0	0	1	7	2	0	2	3	2	99
.066	0	2	16	1	0	0	0	63	4	0	0	1	7	3	3	0	4	2	0	15	0	5	126
.068	5	77	49	0	2	0	3	229	4	0	3	6	45	1	2	0	26	1	1	10	9	0	473
.070	1	24	21	0	5	1	0	96	6	0	3	1	25	1	0	0	9	1	0	12	8	9	223
.072	2	73	20	0	6	1	4	178	4	0	1	2	11	0	0	1	16	1	0	12	8	0	340
.076	6	689	21	0	5	4	3	90	0	1	0	2	0	0	4	0	2	0	0	4	7	20	858
.080	7	142	11	0	0	0	6	36	3	0	0	2	1	0	0	0	4	0	0	0	7	0	219
.084	11	361	3	0	1	1	0	131	6	1	0	0	1	0	4	0	3	0	1	2	0	26	552
.088	1	324	3	0	0	0	1	104	3	1	0	0	0	0	0	0	7	0	0	3	0	8	455
.094	0	50	2	0	1	0	0	66	14	0	0	0	0	0	0	0	1	0	0	5	4	4	147
.098	2	107	2	0	0	0	0	907	20	0	0	2	1	0	1	0	4	0	23	12	4	12	1097
11.102	6	33	4	0	0	0	0	99	7	0	0	0	0	0	0	0	1	0	0	12	1	5	168
.106	1	10	2	0	1	0	2	22	0	0	1	0	0	0	0	0	0	2	0	6	0	1	48
.110	8	9	7	0	0	0	0	57	0	1	0	0	0	0	0	0	1	0	0	0	3	1	87
.114	1	57	43	0	0	0	1	243	1	0	0	1	0	0	0	1	3	0	0	5	1	1	358
.118	4	7	6	0	0	0	0	84	0	0	0	3	0	0	0	0	0	1	0	2	2	3	112
.120	1	3	2	0	0	0	0	9	0	0	0	1	0	0	0	0	0	0	1	2	3	0	22
.124	0	25	11	0	0	0	0	66	0	0	0	0	0	0	1	0	5	0	0	0	0	3	111
.128	0	98	6	0	0	0	2	98	4	1	0	1	0	0	0	0	10	1	0	3	4	2	230
.130	0	7	6	0	2	0	1	29	2	0	0	0	0	0	0	0	0	1	0	0	3	0	51
.132	0	8	4	0	1	1	5	16	0	0	0	0	0	0	0	0	0	2	0	1	4	0	42
.134	0	28	0	0	0	0	2	109	4	0	0	1	0	4	171	0	0	0	0	3	8	4	334
.136	0	46	33	0	0	2	2	168	9	2	6	4	0	0	2	0	0	0	0	0	7	1	282
.138	0	8	34	0	0	0	5	21	4	0	0	2	6	0	0	1	0	3	0	2	1	0	87
.140	0	5	9	0	0	0	0	12	0	2	2	0	0	0	0	1	0	0	0	0	1	1	33
.142	0	13	7	0	0	0	0	69	8	1	0	1	1	0	0	0	0	0	1	2	0	7	110
.146	0	22	3	0	0	0	0	17	0	0	0	0	0	0	3	1	0	0	0	0	0	3	49
.148	0	77	2	0	0	0	0	13	1	0	0	1	1	0	0	0	0	0	0	0	2	6	103
.150	0	82	2	0	0	1	2	38	2	0	0	0	0	0	4	0	0	0	0	0	0	10	141
.152	0	138	4	0	0	0	1	115	3	0	0	0	1	0	1	0	0	0	0	4	1	0	268
.154	0	8	4	0	0	2	0	15	1	0	0	2	1	0	0	0	0	0	0	5	0	7	45
.156	0	88	3	0	0	0	2	29	4	0	0	2	2	0	0	0	0	0	0	1	5	21	157
.158	0	40	2	0	1	6	0	103	6	0	0	1	3	0	0	1	0	1	0	4	2	29	199
.159	0	102	2	0	0	1	1	117	9	0	1	2	0	1	0	1	10	4	0	3	5	27	286
.161	0	12	3	0	0	1	0	10	0	0	0	0	2	0	0	0	0	0	0	1	0	2	31

APPENDIX TABLE 1.—Counts of fish larvae, tabulated by family, for all stations occupied on EASTROPAC I.—*Continued.*

STATION NUMBER	Bathylagidae	Gonostomatidae	Sternoptychidae	Astronesthidae	Chauliodontidae	Idiacanthidae	Other Stomiatoidei	Myctophidae	Paralepididae	Scopelarchidae	Eel leptocephali	Melamphaeidae	Bregmacerotidae	Exocoetidae	Scombridae	Gempylidae-Trichiuridae	Nomeidae	Bramidae	Chiasmodontidae	Other identified larvae	Unidentified larvae	Disintegrated larvae	Total fish larvae
11.163	0	8	1	0	0	0	2	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	14
.167	0	30	0	0	0	0	1	20	1	0	0	0	0	0	1	0	0	0	0	0	3	0	56
.169	0	4	1	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	9
.171	0	11	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	13
.173	0	9	0	0	0	0	0	5	0	1	0	0	0	0	0	0	0	0	1	0	0	0	16
.175	0	2	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	1	1	0	0	8
.177	0	5	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	2	0	1	11
.179	0	5	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	1	0	0	19
.181	0	13	3	0	0	0	0	13	1	0	0	0	0	0	0	0	0	0	0	1	0	0	31
.183	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	8
.185	0	5	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
.187	0	22	1	0	0	0	1	24	0	1	0	0	0	1	0	0	0	0	0	1	0	1	52
.189	0	21	1	0	0	0	0	19	0	0	0	0	0	0	0	0	0	1	0	0	0	1	43
.191	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4
.195	0	14	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18
.197	0	45	1	0	0	0	1	60	3	0	0	0	1	0	2	0	0	0	0	6	0	5	124
.199	0	6	0	0	0	1	0	9	0	0	0	1	0	0	1	0	0	0	0	3	0	5	26
11.201	0	2	2	0	0	0	0	8	0	0	1	0	1	0	0	0	0	0	0	1	0	0	15
.203	0	24	1	0	0	0	0	17	1	0	0	0	1	0	0	0	0	0	0	2	0	4	50
.205	0	53	1	0	0	1	3	40	2	0	0	0	7	0	0	0	0	0	0	0	0	5	112
.207	0	15	0	0	0	1	0	21	2	0	0	0	0	0	0	0	0	0	0	1	0	7	47
.209	0	7	1	0	0	1	0	12	2	3	0	1	4	0	0	0	0	0	0	2	1	2	36
.211	0	39	5	0	0	0	1	28	1	0	0	1	1	0	0	0	0	0	0	2	6	5	89
.213	0	37	5	0	0	0	3	71	3	2	0	0	3	0	4	1	0	0	0	2	4	1	136
.215	0	5	7	0	0	0	0	44	4	0	0	0	6	0	3	0	0	0	0	2	4	5	80
.217	0	8	7	0	0	0	1	16	0	0	0	1	4	0	0	0	0	1	0	3	0	1	42
.219	0	2	15	0	0	0	0	10	1	0	0	0	6	0	1	1	1	0	0	0	2	1	40
.221	0	56	35	0	0	0	0	74	6	2	3	2	6	0	1	0	2	2	0	1	3	1	194
.223	0	13	32	1	0	0	0	20	0	0	1	3	5	0	0	0	0	0	0	0	0	1	76
.226	0	5	4	0	0	1	0	7	0	1	3	1	3	0	0	0	0	0	0	0	0	0	25
.228	0	3	12	1	0	2	0	16	2	0	2	3	4	0	0	1	0	0	0	1	4	3	54
.234	2	17	19	0	0	0	0	46	1	2	0	1	0	0	0	1	0	0	0	6	5	17	117
.238	0	8	7	0	1	0	1	10	0	0	0	1	0	0	0	0	0	2	0	1	0	13	44
.242	4	50	20	1	1	0	0	95	1	1	0	2	0	1	0	0	2	2	1	5	3	6	195
.246	2	52	6	0	4	0	0	198	1	1	0	0	0	0	0	0	0	1	0	4	3	2	274
.250	1	20	6	0	0	0	0	57	1	0	0	2	0	0	0	0	2	0	0	6	0	5	100
.254	0	20	1	0	0	0	2	149	6	1	0	0	0	2	0	0	2	0	7	2	8	23	223
.258	3	54	6	0	0	0	0	108	9	0	0	2	0	0	0	0	0	0	0	2	3	2	189
.262	2	68	1	0	0	0	3	85	9	0	0	0	0	0	0	0	2	0	0	0	2	3	175
.266	3	33	5	0	0	0	0	38	1	0	0	0	0	0	0	0	5	0	0	0	4	0	89
.270	4	19	8	0	0	0	0	17	0	0	0	0	0	0	7	0	0	0	0	1	6	4	66
.278	13	155	13	0	0	1	0	116	3	0	1	1	4	0	0	0	1	0	0	2	4	3	317
.282	1	27	4	0	1	1	1	82	6	0	5	0	7	0	0	0	0	3	1	3	5	4	151
.285	9	10	34	0	0	1	1	30	5	0	3	1	13	1	0	0	1	0	0	5	3	25	142
.287	1	18	13	0	0	3	2	87	8	1	4	5	13	0	0	0	0	0	0	5	5	7	172
.289	0	17	18	0	0	4	1	131	2	0	3	10	6	0	0	0	0	0	0	25	2	10	229
.291	0	2	19	0	0	1	0	39	0	0	2	6	10	0	0	0	1	0	0	5	0	6	91
.293	7	3	46	0	0	1	1	50	2	0	1	5	5	0	6	0	9	3	1	16	2	8	166
.295	10	15	40	0	0	0	0	130	4	0	0	4	0	0	1	2	12	1	0	7	3	3	232
.297	5	12	3	0	0	0	0	297	4	0	0	1	4	0	3	2	2	0	1	5	1	9	349
.299	27	2	15	0	0	0	0	29	0	0	0	4	0	0	5	0	4	1	0	4	0	2	93
11.301	1	13	0	0	0	6	0	8	0	1	0	2	1	0	2	0	2	1	0	4	0	3	44
.303	12	47	0	0	1	8	0	44	0	0	0	4	1	0	0	0	0	1	0	2	0	7	127
.306	4	64	0	0	0	3	0	40	0	0	0	4	1	0	1	0	0	0	1	1	0	4	123

APPENDIX TABLE 1.—Counts of fish larvae, tabulated by family, for all stations occupied on EASTROPAC I.—*Continued.*

STATION NUMBER	Bathylagidae	Gonostomatidae	Sternoptychidae	Astronesthidae	Chauliodontidae	Idiacanthidae	Other Stomiatoidei	Myctophidae	Paralepidae	Scopelarchidae	Eel leptocephali	Melamphaeidae	Bregmacerotidae	Exocoetidae	Scombridae	Gempylidae-Trichiuridae	Nomeidae	Bramidae	Chiasmodontidae	Other identified larvae	Unidentified larvae	Disintegrated larvae	Total fish larvae
11.308	1	6	2	0	1	0	0	13	0	1	0	2	8	0	0	0	1	0	1	3	0	5	44
.310	4	6	2	0	1	0	0	15	0	1	0	6	10	0	0	0	0	0	1	2	2	3	53
.312	0	62	3	0	0	0	0	26	2	0	0	3	1	0	0	0	0	0	0	2	0	1	100
.314	5	32	2	0	0	1	1	27	0	1	0	1	0	0	0	0	0	1	0	1	1	1	74
.316	0	3	3	0	0	0	1	8	0	0	0	3	2	0	0	0	0	3	0	2	1	0	26
.318	0	3	13	0	0	0	0	34	0	1	0	1	2	0	0	5	0	0	0	1	0	1	61
.320	1	10	5	0	0	2	0	11	1	0	0	0	2	0	0	1	0	0	0	1	0	6	40
.322	0	35	11	0	0	2	1	115	0	10	0	3	1	0	0	0	0	0	0	1	1	6	186
.324	0	21	1	0	1	1	0	13	1	1	0	1	4	0	0	1	0	0	0	0	0	3	48
.326	0	36	3	0	0	1	1	31	0	1	0	1	4	0	0	2	0	0	0	0	0	1	81
.328	0	40	7	0	0	4	1	55	2	3	0	5	2	0	0	0	0	0	0	0	0	3	122
12.002	3	13	0	0	0	21	1	37	1	4	0	2	0	0	0	0	0	0	0	0	0	1	83
.004	3	12	0	0	0	32	3	85	1	2	0	3	3	0	0	1	0	0	0	4	0	3	152
.006	2	15	1	0	1	29	5	33	5	1	0	2	2	0	0	0	0	0	1	24	0	2	123
.008	3	65	0	0	0	17	2	88	1	9	0	0	1	0	0	0	2	0	0	12	0	3	203
.010	8	98	0	0	0	22	0	121	1	1	0	7	2	0	0	0	0	0	0	6	1	2	269
.012	4	24	0	0	0	10	1	31	6	1	0	1	1	0	0	0	0	1	0	8	0	2	90
.014	4	38	0	0	0	8	2	23	5	0	0	4	1	0	0	1	3	0	0	8	0	9	106
.016	8	182	0	0	0	10	4	69	6	4	0	2	1	0	1	0	3	0	0	9	0	2	301
.018	0	199	0	0	0	10	7	137	3	2	0	2	1	1	0	0	1	0	0	7	0	0	370
.020	3	23	0	0	0	5	4	74	4	0	0	4	1	0	0	1	2	0	0	4	1	1	127
.022	0	21	0	0	0	0	1	16	6	0	0	0	1	1	0	0	0	0	0	5	0	5	56
.024	3	242	0	0	0	0	32	97	6	0	0	1	0	0	0	0	0	0	0	13	1	5	400
.026	4	101	0	0	0	1	3	121	6	3	0	4	1	0	0	0	3	0	2	19	0	0	268
.028	0	32	0	0	0	0	3	13	3	0	0	4	0	2	3	0	3	0	0	8	2	0	73
.030	6	12	0	0	0	1	0	24	3	0	0	0	6	0	1	0	14	0	0	7	1	3	78
.032	0	13	0	0	0	0	1	20	2	0	1	1	12	0	7	0	3	0	1	23	0	314	398
.033	3	36	0	0	0	2	4	87	5	1	2	2	533	0	6	0	0	0	0	38	5	4	728
.035	1	73	0	0	0	0	4	23	2	1	0	1	70	5	2	0	4	0	1	18	0	3	208
.037	9	11	0	0	0	3	1	36	3	1	0	0	2	0	3	0	2	0	0	0	0	0	71
.039	4	3	0	0	0	10	0	17	2	3	1	1	5	3	0	0	0	0	0	0	0	1	50
.041	3	22	0	0	0	6	3	108	4	1	2	1	3	3	1	0	0	0	0	8	0	2	167
.043	0	28	0	0	0	16	2	94	22	2	0	1	16	6	1	0	1	0	0	4	0	7	200
.045	0	7	0	0	0	4	0	33	2	2	0	1	5	3	0	0	0	0	0	3	0	3	63
.047	1	4	0	0	0	4	0	61	5	2	0	1	21	4	1	2	1	0	0	3	6	5	121
.049	2	54	0	0	0	6	1	61	2	2	0	2	6	0	2	0	1	0	0	2	0	6	147
.051	0	68	0	0	0	7	1	51	1	0	1	1	2	0	0	0	3	0	0	1	0	2	138
.053	1	18	0	0	0	2	0	6	1	0	0	3	2	0	2	0	2	1	0	1	1	0	40
.055	0	7	0	0	0	1	1	7	4	0	0	2	0	0	0	0	2	0	0	2	0	0	26
.057	2	13	0	0	0	2	0	37	6	0	0	2	0	0	0	0	4	1	0	0	1	0	68
.059	21	78	11	0	0	0	0	99	2	0	2	4	0	0	0	0	1	0	1	4	0	1	224
.061	8	6	16	0	0	1	0	41	0	0	0	0	0	0	0	0	0	0	0	0	0	4	76
.063	8	0	32	0	0	0	0	109	1	0	0	4	0	0	0	0	0	0	0	1	2	3	160
.065	11	47	70	0	1	0	2	614	0	0	0	1	0	0	0	0	1	0	0	5	3	2	757
.067	2	35	57	0	3	0	1	366	1	0	0	2	0	3	19	0	45	0	0	13	0	3	550
.069	5	18	50	0	1	0	2	227	0	2	0	2	1	0	2	0	15	1	0	13	0	4	343
.071	9	18	52	0	4	2	0	71	2	0	0	1	7	0	0	0	4	0	1	5	2	5	183
.075	19	126	74	1	8	0	2	294	3	0	0	1	0	2	0	0	20	0	0	10	7	14	582
.077	13	26	13	0	0	0	0	110	3	0	0	2	2	2	1	0	2	0	1	6	11	8	200
.079	17	48	14	0	0	0	0	129	3	2	0	1	6	2	42	0	3	0	0	7	2	26	302
.081	29	75	46	0	1	0	0	389	4	1	0	0	0	2	31	1	68	0	0	4	0	85	736
.084	14	11	45	0	0	0	0	207	7	0	0	2	0	0	9	0	7	0	0	0	1	8	311
.087	13	16	12	0	0	0	0	64	8	0	0	0	0	0	1	0	0	0	0	1	0	2	117

APPENDIX TABLE 1.—Counts of fish larvae, tabulated by family, for all stations occupied on EASTROPAC I.—*Continued.*

STATION NUMBER	Bathylagidae	Gonostomatidae	Sternoptychidae	Astronesthidae	Chauliodontidae	Idiacanthidae	Other Stomiatoidei	Myctophidae	Paralepididae	Scopelarchidae	Eel leptocephali	Melamphaeidae	Bregmacerotidae	Exocoetidae	Scombridae	Gempylidae-Trichiuridae	Nomeidae	Bramidae	Chiasmodontidae	Other identified larvae	Unidentified larvae	Disintegrated larvae	Total fish larvae
12.090	4	16	1	0	0	0	0	18	5	0	0	0	0	0	0	0	0	0	0	2	0	0	46
.092	0	50	3	0	0	0	0	71	9	0	0	0	0	0	0	0	0	0	0	1	1	16	151
.094	3	133	1	0	0	0	3	377	38	0	0	2	0	0	0	0	0	0	5	0	0	0	562
.097	3	61	4	0	0	0	0	101	16	1	0	0	0	0	0	0	0	0	0	2	0	19	207
12.100	12	14	11	0	0	0	3	56	5	1	0	1	0	0	1	0	0	0	0	6	1	11	122
.103	0	37	23	0	0	0	0	124	3	0	0	0	0	0	0	0	0	0	0	0	1	4	192
.106	26	41	33	0	0	1	0	319	5	0	0	0	0	1	4	0	6	0	0	6	3	7	452
.109	1	23	14	0	0	0	0	65	14	0	0	0	0	0	0	0	18	0	0	3	0	3	141
.112	6	5	17	0	0	0	0	32	1	0	0	0	0	0	0	0	0	0	0	1	1	4	67
.115	17	12	55	0	0	0	0	72	8	0	0	4	0	0	36	2	10	0	0	8	1	10	235
.118	0	159	9	0	0	0	0	107	6	1	0	0	0	2	11	7	18	1	0	7	0	2	330
.120	0	6	57	0	0	0	0	15	3	0	0	2	0	0	3	1	1	0	0	0	0	4	92
.122	0	5	36	0	2	0	0	30	2	0	0	0	0	0	0	0	0	0	0	0	4	3	82
.124	0	8	24	0	0	0	0	27	0	0	0	1	2	0	0	0	0	0	0	1	0	3	66
.126	0	22	17	0	14	0	0	108	0	0	0	1	0	2	0	0	0	0	0	1	1	6	172
.128	0	8	8	0	1	0	0	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	66
.130	0	0	3	0	2	0	0	12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	18
.132	0	7	8	0	0	0	0	8	0	0	0	0	0	0	0	0	1	0	0	0	0	0	24
.134	0	28	11	0	0	0	1	20	1	0	0	0	0	0	0	0	0	0	0	0	0	1	62
.136	0	16	17	0	0	0	0	19	1	0	0	0	0	0	0	0	0	0	0	0	1	2	56
.138	0	12	6	0	0	0	0	10	3	0	1	0	2	0	0	0	0	0	0	0	0	2	36
.140	0	21	9	0	0	0	1	69	0	0	0	2	0	11	2	0	0	0	0	3	2	0	120
.142	0	110	11	0	1	0	1	84	11	3	2	4	3	1	3	0	0	0	0	0	1	4	241
.144	1	162	37	0	1	0	0	72	7	1	2	0	0	1	0	1	0	0	0	1	3	3	292
.146	0	13	1	0	1	1	0	11	1	1	0	0	0	0	0	0	0	0	0	1	0	0	30
.148	0	6	6	0	0	1	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	2	26
.150	0	36	0	1	0	0	2	86	1	0	0	0	0	0	17	3	0	0	0	1	4	0	151
.152	0	16	3	0	0	2	0	37	0	0	0	0	1	0	0	1	0	0	0	2	0	7	69
.154	0	11	0	0	0	0	0	12	0	1	0	0	4	0	0	0	0	0	0	0	1	2	31
.156	0	8	0	0	0	0	1	14	1	0	0	0	0	0	0	0	0	0	0	3	0	0	27
.158	0	50	1	0	0	0	0	41	4	1	0	1	0	0	0	1	0	0	0	1	0	0	100
.160	0	19	0	0	0	0	1	19	0	0	0	0	0	1	0	0	0	0	0	0	0	2	42
.162	0	1	0	0	0	0	0	5	0	0	1	0	0	0	0	0	0	0	0	1	0	0	8
.164	0	42	0	0	0	0	1	36	1	0	1	3	0	0	0	0	0	0	0	1	0	0	85
.184	0	49	25	0	0	1	0	45	4	5	0	1	0	0	0	0	0	0	0	1	1	1	133
.186	0	2	20	0	7	0	1	5	1	0	0	0	0	0	0	0	0	0	0	1	0	0	37
.188	0	4	31	0	2	0	1	8	3	0	0	1	2	0	0	1	0	0	0	0	0	3	56
.190	0	11	0	0	0	0	1	6	0	0	0	0	0	0	2	0	0	0	0	0	1	1	22
.192	0	27	7	0	0	0	0	45	3	1	0	1	0	1	0	0	0	0	0	0	2	1	88
.194	0	5	3	0	0	0	0	16	0	1	0	0	2	0	0	0	0	0	0	0	1	2	30
.196	0	5	34	0	10	0	0	22	0	0	0	5	0	0	0	0	3	0	0	3	8	7	97
.198	0	2	44	0	1	0	0	12	0	0	0	5	0	0	0	0	1	0	0	1	0	2	68
12.200	0	6	8	0	0	0	0	36	1	0	0	0	0	1	14	0	5	0	0	1	3	4	79
.203	1	4	38	0	0	0	0	91	2	0	0	0	0	0	1	0	0	0	0	0	0	3	140
.206	4	15	14	0	0	0	1	36	2	0	0	3	0	0	1	0	0	1	0	4	0	2	83
.209	4	6	35	0	0	0	0	70	4	0	0	1	0	0	2	0	0	0	0	6	0	1	129
.212	16	34	21	0	0	0	0	300	8	0	0	1	0	0	5	0	0	0	0	3	6	8	402
.215	7	45	23	0	0	0	0	202	6	0	3	0	0	0	12	0	0	0	0	7	0	3	308
.218	1	22	23	0	0	0	0	127	8	1	0	1	0	0	6	0	1	1	0	12	1	8	212
.221	2	44	13	0	0	0	0	209	24	2	0	2	0	0	0	0	1	0	4	8	4	17	330
.224	0	251	11	0	0	0	3	1089	66	5	0	2	0	0	2	0	1	0	10	13	0	10	1463
.227	1	94	14	0	0	0	3	162	27	0	0	1	1	1	1	0	0	0	1	3	5	22	336
.230	3	5	3	0	0	0	0	49	5	1	0	1	0	0	0	0	0	0	0	8	0	3	78
.233	45	52	24	0	0	0	2	250	10	1	0	2	0	0	0	0	0	0	0	3	0	1	390

PPENDIX TABLE 1.—Counts of fish larvae, tabulated by family, for all stations occupied on EASTROPAC I.—*Continued.*

STATION NUMBER	Bathylagidae	Gonostomatidae	Sternoptychidae	Astronesthidae	Chauliodontidae	Idiacanthidae	Other Stomiatoidei	Myctophidae	Paralepididae	Scopelarchidae	Eel leptocephali	Melamphaeidae	Bregmacerotidae	Exocoetidae	Scombridae	Gempylidae-Trichiuridae	Nomeidae	Bramidae	Chiasmodontidae	Other identified larvae	Unidentified larvae	Disintegrated larvae	Total fish larvae
12.235	25	59	11	0	3	0	4	280	11	0	1	1	0	0	11	0	6	0	0	2	0	5	419
.238	17	39	56	0	4	1	3	225	2	3	0	5	4	0	18	0	10	0	0	0	4	5	396
.240	11	19	70	0	3	0	7	54	2	0	0	1	5	0	24	0	10	0	0	6	1	10	223
.242	1	1	44	0	0	1	2	25	1	0	1	2	4	2	12	0	4	2	0	6	3	5	116
.244	3	14	99	1	3	2	2	105	3	2	0	1	8	1	10	0	14	1	0	29	3	2	303
.246	11	3	42	1	0	0	0	248	3	0	1	4	0	1	8	2	5	0	0	14	2	3	348
.248	1	6	8	0	1	0	1	51	0	0	0	1	1	0	1	0	1	0	0	4	0	2	78
.250	1	8	9	0	0	0	0	54	1	0	0	5	6	0	0	0	1	0	0	1	0	3	89
.252	1	3	5	0	0	1	0	44	2	0	0	1	1	0	0	0	0	0	0	0	0	6	64
.254	1	5	13	0	0	2	0	84	5	0	0	0	1	0	0	0	0	0	0	1	0	1	113
.256	3	1	15	0	0	0	2	23	5	0	0	0	5	0	0	0	0	0	0	1	0	1	56
.258	0	0	26	0	0	0	0	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	69
.260	2	20	4	0	0	1	0	74	4	2	0	4	0	0	0	1	1	0	0	4	0	3	120
.262	2	102	0	0	0	7	3	161	10	4	0	0	3	0	0	1	0	0	0	2	0	0	295
.264	2	20	0	0	0	29	1	26	10	0	0	3	8	0	0	0	0	0	0	3	2	6	110
.265	3	18	0	0	0	32	1	54	5	7	0	2	17	0	0	0	2	0	0	1	2	1	145
.268	0	105	0	0	0	14	1	156	6	6	0	0	4	0	0	0	5	0	0	12	1	6	316
.270	1	29	0	0	0	17	1	60	6	4	0	2	7	0	0	0	0	0	0	3	1	3	135
.272	4	43	0	0	0	6	2	81	4	1	0	5	11	0	0	1	0	0	0	3	5	2	168
.274	0	40	0	0	0	36	1	85	5	1	0	8	4	0	0	0	1	0	0	1	1	4	187
.276	0	138	0	0	0	6	0	20	0	0	0	0	1	0	0	1	0	0	0	0	0	1	167
.278	1	165	0	0	0	1	2	45	0	0	0	1	3	0	0	0	0	0	0	0	1	0	219
.280	0	22	0	0	0	0	0	5	0	0	0	1	0	0	0	0	0	0	0	0	0	1	29
.282	1	23	0	0	0	0	0	8	0	0	0	1	1	0	0	0	0	0	0	0	1	0	35
.284	0	120	0	0	0	0	2	16	0	0	0	0	0	0	0	0	0	0	0	0	0	1	139
13.001	8	93	108	0	1	8	0	41	0	1	0	6	0	0	1	0	0	0	0	0	1	6	274
.003	14	1165	39	0	2	10	1	385	14	1	0	9	0	0	0	0	2	0	0	11	0	4	1657
.005	54	310	18	0	0	11	3	1075	0	1	0	14	0	0	3	0	1	0	0	7	0	6	1503
.007	9	13	38	0	2	4	3	133	0	0	0	10	0	0	7	0	2	0	0	4	0	0	225
.009	9	10	15	0	1	0	1	494	0	0	0	7	0	0	7	0	0	0	0	1	0	5	550
.011	6	2	15	0	0	1	1	374	0	0	0	0	0	0	0	0	0	0	0	2	0	0	401
.013	18	9	5	0	0	0	0	207	0	0	0	1	1	1	1	0	0	0	0	5	0	3	251
.015	4	1	21	0	0	0	0	479	0	0	0	2	0	0	4	0	0	0	0	2	0	0	513
.017	16	63	20	0	1	0	2	559	0	0	0	3	0	5	8	0	0	0	0	3	5	3	688
.019	9	82	19	0	0	2	0	1219	0	0	9	5	62	10	106	0	2	0	0	275	48	12	1860
.021	4	2	0	0	0	0	0	409	0	0	1	1	176	0	24	0	0	0	0	58	6	9	690
.022	1	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0	0	0	5
.028	4	6	0	0	0	0	0	2	0	0	1	0	1	0	1	0	0	1	0	0	0	0	16
.030	7	0	0	0	0	0	0	24	0	0	0	7	2	0	7	0	0	0	0	9	0	0	56
.032	0	24	0	0	0	0	0	44	4	0	0	4	8	0	52	0	4	0	0	36	12	0	188
.034	23	61	4	0	0	0	2	158	0	0	0	4	0	6	43	0	7	1	1	46	8	3	367
.036	8	0	2	0	0	0	0	13	0	0	1	3	0	2	0	0	1	0	0	1	0	0	31
.038	28	0	20	0	0	0	0	142	0	0	0	8	0	0	2	0	0	0	0	2	0	10	212
.040	20	17	65	0	0	0	4	469	0	1	2	2	1	0	20	0	0	0	0	10	0	10	621
.042	11	14	85	0	1	0	0	307	0	0	0	3	0	1	4	0	4	0	0	15	0	3	448
.044	10	14	73	0	0	3	1	109	0	1	0	3	0	0	2	0	1	0	1	1	0	1	220
.046	10	78	95	0	1	5	10	105	11	0	0	6	1	0	1	0	3	0	0	3	2	16	347
.048	29	311	177	0	3	6	5	300	22	0	2	12	1	1	1	3	44	0	0	6	0	15	948
.050	10	41	68	0	0	8	1	133	2	0	0	5	0	0	0	0	5	0	0	1	0	3	277
.052	13	199	73	0	0	3	1	79	24	0	0	6	1	0	0	0	4	0	0	22	4	26	455
.054	14	91	26	0	0	1	4	77	24	0	0	2	2	3	11	17	5	0	1	9	7	8	302
.056	33	513	10	0	0	0	18	144	28	0	0	2	1	0	0	2	7	0	0	15	9	4	786
.058	6	338	9	0	0	0	2	83	10	0	0	3	0	0	7	0	3	0	0	0	3	6	470

APPENDIX TABLE 1.—Counts of fish larvae, tabulated by family, for all stations occupied on EASTROPAC I.—*Continued.*

STATION NUMBER	Bathylagidae	Gonostomatidae	Sternoptychidae	Astronesthidae	Chauliodontidae	Idiacanthidae	Other Stomiatoidei	Myctophidae	Paralepididae	Scopelarchidae	Eel leptocephali	Melamphaeidae	Bregmacerotidae	Exocoetidae	Scombridae	Gempylidae-Trichiuridae	Nomeidae	Bramidae	Chiasmodontidae	Other identified larvae	Unidentified larvae	Disintegrated larvae	Total fish larvae
.060	5	26	0	0	0	0	0	59	4	0	0	1	0	0	18	0	0	0	0	2	3	2	120
.062	7	8	1	0	0	0	0	44	5	0	1	0	0	0	1	0	0	0	0	8	5	3	83
.064	15	71	6	0	0	0	2	274	21	0	1	2	0	0	1	0	0	0	1	0	5	7	406
.065	2	72	6	0	0	0	4	31	6	0	0	1	0	0	0	0	0	0	0	1	4	1	128
.067	7	54	3	0	0	0	1	34	6	0	0	1	0	0	0	0	0	0	0	1	0	0	107
.069	37	60	33	0	0	1	6	99	7	0	0	7	0	0	1	0	0	0	0	3	0	3	257
.071	37	572	8	0	1	5	6	318	9	0	0	8	0	1	14	6	3	0	1	13	7	3	1015
.073	42	167	53	0	2	27	1	172	27	0	0	11	0	0	3	7	10	1	1	16	7	8	555
.075	8	21	3	0	1	0	0	39	25	0	0	6	0	0	1	2	1	1	0	1	0	4	113
.077	0	59	38	0	0	0	2	89	14	2	0	1	0	0	5	3	3	0	1	2	2	36	257
.079	0	135	43	0	0	0	0	69	3	3	2	1	0	0	5	0	6	0	0	1	0	0	268
.081	2	164	13	0	0	0	1	16	2	0	1	0	0	0	0	8	4	0	0	1	0	3	215
.083	5	43	4	0	0	0	0	17	1	0	0	6	0	0	0	1	0	0	0	0	0	1	78
.085	0	2	1	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20
.087	0	66	6	0	0	1	0	37	0	1	0	0	1	0	0	0	0	0	0	3	0	0	115
.089	0	26	29	0	0	0	0	105	2	0	0	1	0	0	0	0	0	0	2	3	0	15	183
.091	0	11	2	0	0	1	1	49	6	0	0	3	2	0	2	0	0	1	1	3	2	17	101
.093	0	3	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	2	13
.095	6	146	4	1	0	29	3	195	1	0	2	4	7	0	10	7	0	0	6	12	2	4	439
.097	3	103	11	0	0	7	2	205	2	2	0	6	4	0	1	5	0	1	4	9	2	1	368
.099	0	16	7	0	1	0	1	48	0	0	0	1	1	0	0	0	0	0	6	1	1	0	83
13.101	3	11	0	0	1	0	0	45	2	3	0	1	7	0	0	7	0	0	0	4	1	0	85
.103	1	162	8	0	1	3	4	255	5	0	0	5	3	0	0	7	0	0	3	14	3	7	479
.105	0	50	4	0	0	1	1	166	2	0	0	3	1	0	0	2	0	1	4	5	2	0	242
.107	0	1	0	0	0	0	0	13	0	0	0	0	0	0	0	1	0	0	1	0	0	0	16
.109	0	12	0	0	0	0	0	27	0	0	0	0	0	0	0	0	0	0	0	2	0	0	41
.111	0	18	1	0	0	0	0	49	1	0	0	1	0	0	0	0	0	0	0	1	0	0	71
.113	0	30	2	0	0	0	1	72	2	0	0	0	2	1	0	0	0	0	0	2	0	0	112
.115	0	8	0	0	0	0	0	25	1	0	0	0	1	0	0	0	0	0	0	1	0	1	37
.117	0	9	4	0	0	0	4	52	1	2	0	1	3	1	0	0	0	0	0	1	1	2	81
.119	0	36	0	0	0	0	4	86	4	0	0	0	0	0	0	4	0	0	0	0	0	0	134
.121	0	17	3	0	0	0	0	22	1	0	0	0	0	0	0	0	0	0	0	0	0	2	45
.123	0	3	2	0	0	0	0	3	1	1	0	2	0	0	0	0	0	0	2	0	0	0	14
.125	0	1	1	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5
.127	0	20	2	0	0	0	3	39	1	1	0	1	1	0	0	0	0	0	0	0	0	1	69
.129	0	11	1	0	0	0	2	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28
.131	0	6	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	3	16
.133	0	5	4	0	0	0	0	9	0	0	1	0	0	0	0	0	0	0	0	0	2	0	21
.135	0	56	1	0	0	0	1	78	2	0	0	1	1	0	0	0	0	0	0	0	0	0	140
.137	0	40	1	0	0	0	0	50	1	0	0	0	0	0	0	2	0	0	0	2	0	0	96
.139	0	12	1	0	0	0	0	8	0	0	0	0	0	0	0	1	0	0	0	0	1	1	24
.141	0	4	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
.143	0	76	2	0	0	0	0	86	1	0	0	1	1	0	0	0	0	0	0	0	6	0	173
.145	0	20	2	0	0	0	2	44	2	0	0	0	2	0	0	0	0	0	0	0	0	0	72
.147	0	17	0	0	0	0	0	33	0	0	0	3	4	0	0	2	0	0	0	3	3	0	65
.149	0	14	6	0	0	0	0	29	0	0	0	2	0	0	0	0	1	0	0	0	0	3	59
.151	0	22	0	0	3	0	1	72	0	1	0	0	0	2	0	0	0	0	0	0	1	1	103
.153	0	103	1	0	1	3	1	394	2	1	1	5	3	0	0	1	0	2	0	17	1	3	539
.155	0	8	4	0	0	0	0	16	0	2	0	2	0	0	0	0	0	0	0	2	4	0	38
.157	0	8	8	0	0	1	0	45	1	0	0	0	1	0	1	0	0	0	0	0	0	2	67
.159	0	12	5	0	0	8	0	53	1	1	0	1	0	0	4	2	0	0	0	2	2	1	92
.161	0	24	6	0	0	0	0	65	3	0	0	0	2	0	0	0	0	0	0	0	0	2	102
.163	0	5	2	0	0	0	0	14	0	0	0	0	1	0	0	0	0	0	0	0	0	0	22
.165	0	4	17	0	0	0	0	24	0	0	0	1	2	0	0	0	0	0	0	0	0	0	48

PPENDIX TABLE 1.—Counts of fish larvae, tabulated by family, for all stations occupied on EASTROPAC I.—*Continued.*

STATION NUMBER	Bathylagidae	Gonostomatidae	Sternoptychidae	Astronesthidae	Chauliodontidae	Idiacanthidae	Other Stomiatoidei	Myctophidae	Paralepididae	Scopelarchidae	Eel leptocephali	Melamphaeidae	Bregmacerotidae	Exocoetidae	Scombridae	Gempylidae-Trichiuridae	Nomeidae	Bramidae	Chiasmodontidae	Other identified larvae	Unidentified larvae	Disintegrated larvae	Total fish larvae
13.167	0	19	11	0	0	0	0	33	0	0	0	0	0	0	0	1	0	0	0	1	0	1	66
.169	0	83	10	0	0	0	0	169	0	0	0	1	0	0	0	0	0	0	0	0	0	1	264
.171	0	18	38	0	0	0	1	104	10	0	0	3	0	0	14	1	0	0	0	2	1	3	195
.173	7	4	10	0	0	3	1	121	2	1	0	3	0	0	6	1	0	0	0	1	0	4	164
.175	22	176	14	0	3	1	0	245	5	0	0	5	0	3	45	1	2	0	0	6	5	2	535
.179	15	111	75	0	0	0	0	133	2	1	0	1	0	1	7	3	4	0	0	2	0	0	355
.183	50	39	39	0	2	3	0	80	13	0	0	15	0	0	7	0	22	1	0	3	2	1	277
.187	43	29	49	0	0	0	3	67	7	0	0	3	0	0	1	2	21	0	1	6	0	4	236
.191	10	148	23	0	0	0	1	126	24	0	0	5	0	1	7	1	18	0	0	8	1	3	376
.195	10	202	2	0	0	0	0	182	2	0	0	0	0	0	0	0	0	1	0	1	0	3	403
.199	5	28	3	0	0	0	0	55	5	0	0	2	0	0	0	0	0	0	1	1	0	2	102
13.203	3	16	2	0	0	0	0	20	2	0	0	0	0	0	0	0	0	0	1	3	0	3	50
.207	11	161	4	0	0	0	0	129	11	0	0	1	0	0	0	0	0	0	0	2	0	1	320
.211	5	36	2	0	0	0	1	68	3	0	0	0	0	0	1	0	0	0	0	0	1	1	118
.215	6	7	5	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	2	27
.219	9	10	14	0	0	0	0	11	0	0	1	0	0	0	0	0	0	0	0	0	0	4	49
.223	2	20	3	0	0	0	0	32	5	0	0	2	0	0	0	0	3	0	0	1	3	1	72
.227	9	38	30	0	0	0	0	121	12	0	1	1	0	4	1	0	3	0	0	0	1	0	221
.231	9	34	35	0	0	0	0	82	0	0	0	1	0	0	0	0	2	0	1	1	0	1	166
.235	9	36	78	0	0	1	1	106	0	2	0	1	0	1	1	1	5	0	0	3	6	7	258
.237	6	47	97	0	1	0	1	189	2	1	0	3	0	0	7	0	7	0	0	3	4	3	371
.239	3	44	58	0	0	0	3	179	0	0	0	1	0	0	0	0	7	0	0	4	0	2	301
.241	2	5	36	0	0	0	0	59	1	0	0	0	0	0	1	0	6	0	0	0	0	4	114
.243	11	13	5	0	0	0	0	93	0	0	0	3	1	0	0	0	5	0	0	1	0	9	141
.245	7	14	11	0	1	0	0	57	3	3	0	2	0	0	0	1	0	0	0	15	0	0	114
.247	9	11	3	0	0	0	0	26	0	2	0	1	0	0	1	0	0	0	0	7	0	0	60
.249	1	3	4	0	0	0	0	46	0	0	0	0	0	0	0	0	0	0	0	1	0	0	55
.251	6	10	9	0	0	1	2	25	15	2	3	1	0	0	3	0	1	1	0	1	0	1	81
.253	20	22	2	0	0	2	4	6	2	0	2	2	0	0	0	0	6	0	0	80	0	0	148
.255	7	29	0	0	0	2	0	29	2	2	0	3	4	1	15	0	0	0	0	29	3	2	128
.257	8	3	0	0	0	0	2	10	3	0	0	1	5	0	0	0	0	0	0	2	0	4	38
.259	17	18	0	0	0	4	0	23	0	0	0	1	2	0	5	0	0	0	0	3	0	6	79
.261	8	37	0	0	0	3	0	13	6	3	0	1	5	0	0	0	1	0	0	44	0	1	122
.263	19	54	0	0	0	4	0	46	1	5	0	3	3	1	11	0	0	0	0	15	1	2	165
.265	6	13	0	0	0	0	8	14	6	1	1	0	5	0	2	0	2	0	0	5	5	1	69
.266	0	2	0	0	0	0	0	14	0	0	0	0	22	0	2	0	0	0	0	8	5	1	54
.268	3	26	0	0	0	7	0	33	5	1	0	1	3	0	1	0	3	0	0	2	4	7	96
.270	4	20	0	0	0	5	4	9	7	1	0	1	1	12	1	0	2	0	0	3	2	6	78
.272	2	3	1	0	0	0	2	13	1	0	0	1	1	0	0	0	1	0	0	1	0	2	28
.274	1	52	0	0	0	21	6	63	15	4	1	8	3	3	2	0	7	0	0	9	2	1	198
.276	5	91	0	0	0	13	3	89	10	0	0	1	3	3	20	0	2	0	0	9	1	0	250
.278	1	21	0	0	0	18	2	7	0	3	0	1	2	0	0	0	1	0	0	0	0	1	59
.280	8	8	0	0	0	27	2	31	2	15	0	0	34	0	0	1	0	0	0	6	0	0	134
.282	0	36	0	0	0	9	6	89	5	20	0	0	7	1	0	0	0	0	0	15	1	0	189
.284	18	61	0	0	0	23	3	34	10	15	0	1	13	2	0	0	0	0	0	3	0	2	185
13.318	13	1	0	0	0	5	0	3	0	2	0	2	5	0	1	0	0	0	0	5	0	0	37
.320	8	16	9	0	0	0	0	18	1	4	1	5	2	0	13	0	0	0	0	23	0	0	100
.322	0	5	0	0	0	0	0	0	0	0	1	0	0	2	9	0	0	0	0	6	0	0	23
.324	10	4	1	0	0	3	0	26	1	0	0	0	1	3	4	0	1	0	0	1	0	0	55
.326	13	10	1	0	0	0	0	44	0	4	0	0	2	0	18	0	0	0	0	4	0	0	96
.328	2	9	1	0	0	0	0	35	2	1	0	5	1	1	7	0	23	0	0	4	3	2	96
.330	4	12	8	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	4	0	0	52
.332	11	2	19	0	0	0	0	63	0	0	0	0	0	0	2	0	0	1	0	1	0	1	100

APPENDIX TABLE 1.—Counts of fish larvae, tabulated by family, for all stations occupied on EASTROPAC I.—*Continued.*

STATION NUMBER	Bathylagidae	Gonostomatidae	Sternoptychidae	Astronesthidae	Chauliodontidae	Idiacanthidae	Other Stomiatoidei	Myctophidae	Paralepididae	Scopelarchidae	Eel leptocephali	Melamphaeidae	Bregmacerotidae	Exocoetidae	Scombridae	Gempylidae-Trichiuridae	Nomeidae	Bramidae	Chiasmodontidae	Other identified larvae	Unidentified larvae	Disintegrated larvae	Total fish larvae
13.334	37	21	17	0	0	0	1	116	2	0	0	3	0	0	1	0	1	0	0	5	3	1	208
.338	9	49	26	0	0	0	0	295	0	0	1	0	0	2	5	0	8	0	0	24	0	3	422
.340	4	11	23	0	0	2	0	47	0	0	0	4	0	0	0	0	4	1	0	4	0	0	100
.342	9	24	21	0	0	2	0	76	4	0	1	3	0	0	4	0	0	0	0	1	0	2	147
14.001	39	97	1	1	1	0	6	867	4	5	2	0	194	0	9	1	12	0	0	261	15	195	1710
.006	32	19	38	0	0	0	1	66	2	0	8	0	2	0	10	0	0	0	0	15	25	8	226
.008	34	4	32	0	0	2	1	86	1	0	2	0	1	0	1	0	2	0	0	25	4	2	197
.010	14	19	40	0	0	4	2	198	1	0	2	3	0	0	0	1	0	0	0	12	2	3	301
.012	6	1	7	0	0	1	1	57	1	0	0	3	1	0	0	2	0	0	0	2	4	4	90
.014	42	4	9	0	0	1	0	67	0	0	1	0	9	0	2	0	0	0	0	30	5	28	198
.016	19	1	20	0	0	0	0	8	0	0	0	2	4	0	2	0	0	0	0	44	16	5	121
.017	17	2	16	0	0	1	0	61	1	0	0	2	0	0	0	0	0	0	0	4	0	1	105
.018	41	48	64	0	0	2	2	424	0	0	0	4	0	0	0	0	5	0	0	24	1	19	634
.020	6	10	12	0	0	0	1	229	1	0	0	2	0	0	0	0	0	0	0	10	0	54	325
.022	7	22	14	0	0	0	3	80	0	0	0	5	1	0	0	0	1	0	0	32	4	0	169
.024	6	0	0	0	0	0	0	47	0	0	1	0	0	1	0	0	0	0	0	29	5	22	111
.027	23	31	42	0	0	0	3	387	0	0	2	7	9	0	6	0	0	0	0	87	34	19	650
.029	24	42	25	0	0	0	5	382	0	1	1	2	6	0	1	3	1	0	0	119	47	26	685
.031	30	43	46	0	0	9	2	594	15	0	2	6	0	0	1	1	3	0	0	75	5	43	875
.033	21	5	0	0	0	0	2	26	1	0	0	1	0	0	0	0	0	0	0	9	3	3	71
.040	48	2	0	0	0	0	2	36	8	0	3	4	0	0	6	0	0	0	1	21	3	21	155
.043	65	17	2	0	0	0	1	159	8	0	0	8	1	0	22	0	1	0	3	15	7	4	313
.047	111	3	4	0	0	0	4	22	3	0	0	2	0	3	9	0	6	0	0	7	0	44	218
.051	225	27	1	1	0	0	5	78	3	0	0	1	0	1	46	0	11	0	1	1	3	25	429
.055	154	2	2	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0	4	0	8	210
.060	139	0	0	0	0	0	0	18	0	0	1	2	0	0	0	0	0	0	0	54	2	15	231
.066	13	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	11	0	1	26
.069	20	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	97	0	0	119
.076	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	11	0	0	15
.078	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.081	2	16	1	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37
.084	2	3	0	0	0	0	0	4	0	0	0	0	0	1	0	0	0	0	0	1	0	2	13
.086	2	0	0	0	1	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	3	13
.088	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
.091	2	40	0	0	0	0	1	43	0	0	0	0	0	0	0	0	0	0	0	3	2	0	91
.095	2	3	0	0	0	0	1	50	0	0	0	0	0	0	0	1	0	0	1	1	0	0	59
.099	2	3	0	0	0	1	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21
14.103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.106	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	11	0	14
.110	0	8	0	0	0	0	0	27	0	0	0	0	0	0	0	0	0	0	0	1	0	1	37
.112	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	5
.114	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
.115	2	6	0	0	1	0	0	5	0	0	0	1	0	0	0	0	0	0	0	2	0	0	17
.117	2	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	5
.118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.120	1	6	0	0	1	0	0	15	0	0	0	0	0	1	1	0	0	0	0	0	0	0	25
.122	2	11	1	0	0	1	0	19	0	0	0	0	0	0	0	1	0	0	0	1	0	0	36
.123	7	23	0	0	0	7	0	51	0	0	0	1	1	0	0	1	0	0	2	9	0	0	102
.124	7	76	0	0	0	6	0	152	0	0	0	0	4	2	0	3	0	0	2	12	0	4	268
.126	3	20	1	0	2	6	0	53	0	1	0	0	3	0	0	2	0	0	3	4	1	15	114
.127	5	5	0	0	0	0	1	22	0	0	0	0	2	0	0	3	0	0	0	3	0	3	44
.128	5	60	0	0	3	9	0	145	0	0	0	0	5	0	0	6	1	0	1	13	0	0	248
.130	3	44	1	0	1	7	0	45	0	0	0	2	2	0	4	3	2	1	5	3	4	15	142

APPENDIX TABLE 1.—Counts of fish larvae, tabulated by family, for all stations occupied on EASTROPAC I.—*Continued.*

STATION NUMBER	Bathylagidae	Gonostomatidae	Sternoptychidae	Astronesthidae	Chauliodontidae	Idiacanthidae	Other Stomiatoidei	Myctophidae	Paralepididae	Scopelarchidae	Eel leptocephali	Melamphaeidae	Bregmacerotidae	Exocoetidae	Scombridae	Gempylidae-Trichiuridae	Nomeidae	Bramidae	Chiasmodontidae	Other identified larvae	Unidentified larvae	Disintegrated larvae	Total fish larvae
14.131	0	14	0	0	0	0	1	2	0	2	0	0	0	0	0	1	0	0	0	0	2	2	24
.132	8	17	3	0	0	0	0	8	1	2	2	3	0	0	0	0	2	2	0	5	1	0	54
.134	0	4	2	0	0	0	0	11	0	0	2	2	0	0	0	2	2	0	0	1	0	1	27
.136	1	18	3	0	0	0	0	43	0	0	0	0	0	0	0	0	0	0	1	0	0	0	66
.138	9	92	32	0	0	0	0	29	1	1	0	0	0	1	9	3	5	0	1	1	1	4	189
.142	1	53	31	0	0	0	4	110	0	0	0	1	0	0	1	2	5	0	0	1	0	4	213
.146	46	111	9	0	2	0	2	176	10	0	0	3	0	1	8	2	17	1	0	2	0	4	394
.150	34	48	13	0	0	0	1	52	4	0	0	4	0	4	5	1	2	1	3	6	0	87	265
.154	34	382	17	0	0	0	0	92	6	0	0	5	0	2	7	0	1	0	1	20	1	2	570
.158	0	224	2	0	0	0	1	30	10	0	0	0	0	0	3	0	6	0	0	27	5	21	329
.164	8	53	0	0	0	0	2	135	39	0	3	0	0	0	6	1	0	0	1	8	2	26	284
.172	1	97	20	0	0	0	0	26	0	0	2	0	0	0	16	0	0	0	0	43	3	1	209
.174	3	37	12	0	0	0	0	26	7	0	0	1	0	0	0	0	0	0	0	12	7	32	137
.177	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	77	5	0	86
.183	1	1	0	0	1	0	0	4	1	0	0	0	0	0	0	0	0	0	0	1	0	2	11
.188	34	168	5	0	0	4	1	261	25	1	5	7	0	3	36	1	3	0	0	5	2	0	561
.194	161	129	1	0	0	3	4	1753	40	0	4	23	0	0	22	2	12	0	0	12	7	24	2197
.195	54	17	0	0	0	2	1	252	24	3	0	1	0	0	0	1	0	0	0	6	0	68	429
.199	15	203	20	0	1	2	0	16	13	3	3	5	0	0	20	0	2	1	1	12	5	4	326
14.203	3	2	12	0	0	0	0	179	2	0	0	1	0	0	1	0	2	0	0	4	0	2	208
.209	5	2	5	0	0	0	0	25	0	0	2	0	1	10	0	0	2	0	0	3	0	1	56
.213	34	96	9	0	1	2	2	206	1	2	1	3	0	1	11	0	2	0	0	6	1	0	378
.218	27	39	1	0	0	1	0	177	0	2	0	1	0	2	4	0	1	0	0	3	1	7	266
.220	2	3	6	0	0	0	0	22	9	0	0	1	0	0	13	0	0	0	0	5	4	21	86
.222	2	5	2	0	1	2	2	49	0	2	1	1	0	0	1	1	0	0	0	1	2	1	73
.224	12	37	19	0	0	0	2	115	2	1	1	1	0	0	8	1	0	0	0	12	4	6	221
.228	2	5	10	0	0	1	0	30	3	2	1	2	1	0	2	0	0	0	0	14	3	0	76
.230	1	5	9	0	1	0	1	41	2	0	0	1	0	0	10	0	0	1	0	8	2	8	90
.232	9	49	23	0	0	0	0	31	1	2	0	3	0	0	12	0	0	0	0	8	0	1	139
.234	9	869	1	0	0	3	8	228	10	0	12	1	0	0	185	9	9	0	0	5	1	350	1748
.236	3	16	3	0	0	1	0	34	2	1	1	3	0	0	10	0	0	0	0	8	1	0	83
.240	21	36	18	0	0	2	0	116	16	2	2	5	1	0	85	1	2	0	0	12	3	8	330
.243	24	28	11	0	0	0	0	44	7	0	1	1	0	1	5	0	1	0	0	3	0	2	128
.247	4	52	9	0	0	2	0	86	9	0	0	0	0	0	1	0	1	0	0	2	2	1	169
.251	11	25	6	0	1	1	0	25	8	0	0	4	0	0	1	0	0	0	0	8	0	1	91
.255	210	86	11	0	1	2	0	227	0	1	0	1	0	0	59	0	2	1	0	8	5	17	631
.259	16	40	6	0	0	4	1	53	0	3	1	6	0	0	0	3	0	2	0	7	3	4	149
.263	2	233	4	0	0	0	0	105	0	0	0	1	0	0	0	0	4	0	0	3	0	2	354
.267	3	33	3	0	0	0	1	8	0	0	0	2	0	0	0	0	0	0	0	6	1	0	57
.276	9	58	0	0	0	1	0	13	0	2	0	3	0	0	0	0	3	0	0	3	3	0	95
.280	7	63	0	0	0	4	2	44	1	0	0	0	0	0	0	6	4	0	0	9	4	10	154
.283	3	13	0	0	2	0	0	22	0	1	0	4	0	0	0	1	0	0	1	2	0	1	50
.287	5	62	12	0	1	0	0	15	0	1	0	2	0	0	0	3	10	1	0	10	0	1	123
.291	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.295	4	1	2	0	0	0	0	65	0	0	0	1	0	0	63	1	1	0	0	8	3	1	150
14.300	287	0	5	0	0	0	2	18	0	0	0	0	0	0	1	0	0	0	0	1	0	8	322
.303	493	10	6	0	0	0	3	200	0	0	0	2	0	0	0	0	0	0	0	9	0	0	723
.306	34	2	1	0	0	0	2	32	8	0	0	6	0	0	0	0	0	0	1	1	0	5	92
.310	91	21	18	0	0	0	3	96	6	0	0	8	0	0	0	0	0	0	0	0	0	5	248
.314	24	25	20	0	0	0	2	59	7	0	0	4	0	0	0	0	0	0	0	2	0	1	144
.318	32	70	39	0	0	9	1	566	0	0	0	4	0	0	1	3	0	0	1	93	0	9	828
.323	11	24	37	0	0	0	3	165	0	0	0	2	0	0	0	0	0	0	0	15	0	5	262
.326	27	66	31	0	0	4	4	659	0	0	2	13	1	0	8	1	0	0	0	49	13	33	911
.330	0	1	3	0	0	0	0	23	1	0	0	0	5	0	0	1	0	0	0	1	0	3	38

APPENDIX TABLE 2.—Myctophid larvae, tabulated by genus or species, for all stations occupied on EASTROPAC I.

STATION NUMBER	Benthosema panamense	Ceratoscopelus townsendi	Diaphus spp.	Diogenichthys laternatus	Diogenichthys atlanticus	Electrona sp.	Gonichthys tenuiculus	Hygophum atratum	Hygophum proximum	Lampadena spp.	Lampanyctus spp.	Lepidophanes pyrsobolus	Lobianchia sp.	Loweina rara	Myctophum spp.	Notolychnus valdiviae	Notoscopelus resplendens	Protomyctophum sp.	Symbolophorus evermanni	Triphoturus spp.	Unidentified myctophids	Disintegrated myctophids	Total myctophids
11.022	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	4
.025	0	1	1	1	0	0	0	0	4	0	4	0	0	0	0	0	0	0	0	0	0	0	11
.027	0	1	1	4	0	0	0	4	0	0	2	0	0	1	0	0	0	0	0	0	1	0	14
.030	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.032	0	0	0	6	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
.034	0	0	2	10	0	0	0	16	0	0	7	0	0	0	0	0	0	0	0	0	0	0	35
.036	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3
.038	0	0	2	10	0	0	0	4	0	0	1	0	0	0	0	0	0	0	0	0	2	2	21
.040	0	0	5	4	0	0	0	39	0	0	1	0	0	0	0	0	0	0	4	0	2	0	55
.044	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
.046	0	0	4	41	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	1	50
.048	0	0	1	6	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	20
.050	0	0	0	33	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	36
.052	0	0	0	56	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	58
.054	0	0	3	147	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	159
.056	0	0	0	56	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	3	67
.058	0	0	0	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	28
.060	0	0	4	53	0	0	1	0	3	0	9	0	0	0	0	0	0	0	1	0	1	0	72
.062	0	0	0	16	0	0	0	0	1	0	2	0	0	0	0	1	0	0	0	0	1	0	21
.064	0	0	2	43	0	0	0	0	0	0	2	0	0	0	0	3	0	0	0	0	1	0	51
.066	0	0	4	14	0	0	2	0	9	0	4	0	0	0	20	3	0	0	4	1	2	0	63
.068	0	0	67	33	1	0	0	0	14	2	4	7	0	4	21	32	1	0	21	8	0	14	229
.070	0	1	15	8	0	0	0	0	6	0	0	0	0	1	48	6	2	0	4	0	0	5	96
.072	0	0	28	6	0	0	0	0	22	1	12	7	0	0	44	21	2	0	24	7	0	4	178
.076	0	0	0	23	0	0	0	0	0	0	27	0	0	0	0	20	5	0	0	1	1	13	90
.080	0	0	1	18	0	0	0	2	1	0	6	0	0	0	3	2	0	0	1	0	1	1	36
.084	0	0	0	63	0	0	0	0	7	0	13	0	0	0	1	3	0	0	2	0	0	42	131
.088	0	0	2	10	0	0	0	1	9	0	67	0	0	1	7	0	2	0	0	2	0	3	104
.094	0	0	5	8	0	0	0	0	4	0	32	0	0	0	9	1	0	0	0	1	4	2	66
.098	0	0	3	107	0	0	2	50	109	1	404	0	12	1	180	8	10	0	9	1	1	9	907
11.102	0	0	0	21	0	0	0	3	26	0	12	0	0	0	26	0	0	0	1	0	0	10	99
.106	0	0	0	6	0	0	0	0	4	0	0	0	0	0	7	0	0	0	4	0	0	1	22
.110	0	0	0	41	0	0	0	1	1	0	3	0	0	0	7	1	0	0	1	1	0	1	57
.114	0	0	0	182	0	0	0	3	9	0	31	0	0	1	11	1	1	0	2	0	2	0	243
.118	0	0	0	70	0	0	0	1	1	0	9	0	0	0	0	0	0	0	0	0	0	3	84
.120	0	0	0	8	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	9
.124	0	0	0	37	0	0	0	2	5	0	17	0	0	1	0	3	0	0	0	0	0	1	66
.128	0	1	0	31	0	0	0	3	1	0	29	0	0	2	0	6	0	0	16	1	0	8	98
.130	0	1	11	0	0	0	0	0	3	0	4	0	0	0	1	0	0	0	0	0	8	1	29
.132	0	4	3	0	0	0	0	0	1	3	0	0	0	0	1	0	0	0	4	0	0	0	16
.134	0	26	39	0	0	0	0	0	0	0	30	0	0	0	0	2	0	0	0	0	6	6	109
.136	0	30	39	0	0	0	0	0	5	4	5	0	0	0	8	2	0	0	60	0	15	0	168
.138	0	0	10	0	1	0	0	0	1	2	1	0	0	0	1	0	0	0	2	1	0	2	21
.140	0	2	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	3	0	1	0	12
.142	0	4	6	0	0	0	0	0	1	0	16	0	0	0	0	0	0	0	31	0	2	9	69
.146	0	10	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	1	17
.148	0	5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	4	0	0	3	13
.150	0	0	4	0	0	0	0	0	3	0	3	0	0	0	0	0	0	0	15	0	0	13	38
.152	0	10	13	0	0	0	0	3	19	1	20	0	0	0	1	0	3	0	43	0	2	0	115
.154	0	0	0	0	0	0	0	0	1	0	6	0	0	0	0	0	0	0	5	0	0	3	15

PENDIX TABLE 2.—Myctophid larvae, tabulated by genus or species, for all stations occupied on EASTROPAC I. —*Continued.*

STATION NUMBER	Benthosema panamense	Ceratoscopelus townsendi	Diaphus spp.	Diogenichthys laternatus	Diogenichthys atlanticus	Electrona sp.	Gonichthys tenuiculus	Hygophum atratum	Hygophum proximum	Lampadena spp.	Lampanyctus spp.	Lepidophanes pyrsobolus	Lobianchia sp.	Loweina rara	Myctophum spp.	Notolychnus valdiviae	Notoscopelus resplendens	Protomyctophum sp.	Symbolophorus evermanni	Triphoturus spp.	Unidentified myctophids	Disintegrated myctophids	Total myctophids
1.156	0	4	0	0	0	1	0	0	9	0	9	0	0	0	0	0	0	0	5	0	0	1	29
.158	0	8	14	0	0	2	0	0	23	0	7	0	0	0	2	0	0	0	27	0	1	19	103
.159	0	19	14	0	0	1	0	0	16	0	17	0	0	0	2	1	0	0	25	0	0	22	117
.161	0	3	0	0	0	0	0	0	2	0	2	0	0	0	1	0	0	0	0	0	0	2	10
.163	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
.167	0	1	5	0	0	0	0	0	1	0	6	1	0	0	2	0	0	0	4	0	0	0	20
.169	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3
.171	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
.173	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	1	0	5
.175	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	4
.177	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
.179	0	2	1	0	0	0	0	2	0	0	7	0	0	0	1	0	0	0	0	0	0	0	13
.181	0	3	1	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	3	13
.183	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.185	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	2	0	4
.187	0	4	0	0	0	0	0	4	0	0	11	0	0	0	0	0	0	0	1	0	0	4	24
.189	0	3	5	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	5	19
.191	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	2
.195	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	1	0	0	0	4
.197	0	14	13	0	0	1	0	0	3	0	7	0	0	0	3	0	0	0	6	0	5	8	60
.199	0	0	0	0	0	0	0	0	0	0	3	0	0	0	1	0	0	0	2	0	0	3	9
1.201	0	1	0	0	0	0	0	0	0	0	1	0	0	0	3	0	0	0	1	0	0	2	8
.203	0	0	4	0	0	0	0	0	0	0	4	0	0	0	4	0	0	0	2	0	1	2	17
.205	0	5	9	0	0	0	0	0	6	0	3	0	0	0	5	0	0	0	8	0	0	4	40
.207	0	7	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	3	0	0	8	21
.209	0	0	1	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	4	0	0	2	12
.211	0	3	0	0	0	0	0	0	13	0	5	0	0	0	0	0	0	0	2	0	0	5	28
.213	0	17	16	0	0	0	0	0	6	0	5	0	0	0	3	0	0	0	17	0	4	3	71
.215	0	4	0	0	0	0	0	0	13	0	8	0	0	0	2	2	0	0	7	0	0	8	44
.217	0	1	2	0	0	0	0	0	5	0	2	0	0	0	0	0	0	0	5	0	0	1	16
.219	0	3	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	3	0	1	0	10
.221	0	0	26	0	0	0	0	0	11	0	4	3	0	0	1	8	0	0	19	0	0	2	74
.223	0	4	0	0	0	0	0	0	3	0	2	0	0	0	2	2	0	0	6	0	1	0	20
.226	0	2	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	2	0	0	1	7
.228	0	0	2	0	0	0	0	0	4	0	0	0	0	0	0	6	1	0	3	0	0	0	16
.234	0	9	1	14	0	0	0	0	7	0	2	0	0	0	1	4	0	0	1	0	0	7	46
.238	0	0	0	3	0	0	0	0	1	0	2	0	0	0	0	0	0	0	2	0	0	2	10
.242	0	0	0	58	0	0	0	2	9	0	13	0	0	1	2	3	0	0	1	2	0	4	95
.246	0	0	1	62	0	0	0	1	14	0	98	0	0	0	16	0	0	0	0	0	0	6	198
.250	0	0	1	17	0	0	0	2	15	0	8	0	0	0	11	1	0	0	0	1	0	1	57
.254	0	1	2	18	0	0	2	1	30	0	4	0	0	0	85	0	0	0	4	0	0	2	149
.258	0	0	0	32	0	0	0	5	1	0	20	0	0	1	0	0	0	0	36	0	11	2	108
.262	0	0	4	57	0	0	0	2	2	0	5	0	0	4	4	2	0	0	0	0	0	5	85
.266	0	1	3	19	0	0	0	0	0	0	1	0	0	1	3	3	0	0	1	1	2	3	38
.270	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	1	2	2	17
.278	0	0	9	51	0	1	0	2	3	0	20	0	2	1	7	13	4	0	0	2	0	1	116
.282	0	0	0	14	0	0	0	0	7	0	19	4	0	0	26	3	0	0	8	1	0	0	82
.285	0	0	0	7	0	0	0	0	6	0	0	0	0	0	6	1	0	0	2	0	0	8	30
.287	0	0	17	2	0	0	0	0	14	1	6	2	0	0	16	18	0	0	5	1	2	3	87
.289	0	0	33	17	0	0	0	0	19	8	4	2	0	0	8	12	2	0	14	0	0	12	131

APPENDIX TABLE 2.—Myctophid larvae, tabulated by genus or species, for all stations occupied on EASTROPAC I. —*Continued.*

STATION NUMBER	Benthosema panamense	Ceratoscopelus townsendi	Diaphus spp.	Diogenichthys laternatus	Diogenichthys atlanticus	Electrona sp.	Gonichthys tenuiculus	Hygophum atratum	Hygophum proximum	Lampadena spp.	Lampanyctus spp.	Lepidophanes pyrsobolus	Lobianchia sp.	Loweina rara	Myctophum spp.	Notolychnus valdiviae	Notoscopelus resplendens	Protomyctophum sp.	Symbolophorus evermanni	Triphoturus spp.	Unidentified myctophids	Disintegrated myctophids	Total myctophids
11.291	0	2	3	13	0	0	0	0	6	0	1	0	0	1	2	3	0	0	0	0	1	7	39
.293	0	0	0	36	0	0	0	0	2	0	2	0	0	1	1	1	0	1	3	0	2	1	50
.295	0	0	7	94	0	0	0	0	4	0	18	0	0	0	0	1	0	1	4	0	0	1	130
.297	0	0	6	263	0	0	0	0	3	0	3	0	0	0	0	0	0	0	1	0	1	20	297
.299	0	1	0	23	0	0	0	0	2	0	2	0	0	0	1	0	0	0	0	0	0	0	29
11.301	0	0	0	5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	8
.303	0	0	0	42	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	44
.306	0	0	0	37	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	40
.308	0	0	0	6	0	0	0	0	0	0	2	0	0	0	0	0	0	0	5	0	0	0	13
.310	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	15
.312	0	0	0	16	0	0	0	1	0	0	1	0	0	0	0	0	0	0	4	0	0	4	26
.314	0	0	2	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	1	1	27
.316	0	0	1	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	4	0	0	0	8
.318	0	0	0	26	0	0	1	0	2	0	5	0	0	0	0	0	0	0	0	0	0	0	34
.320	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0	0	6	11
.322	0	4	2	21	0	0	0	3	55	0	12	0	0	1	2	0	0	0	1	0	0	14	115
.324	0	2	0	2	0	0	0	0	1	1	4	0	0	0	2	1	0	0	0	0	0	0	13
.326	0	0	1	2	0	0	0	0	3	0	17	0	0	0	1	1	0	0	2	0	2	2	31
.328	0	3	2	3	2	0	0	3	16	1	6	0	0	1	0	5	3	2	6	0	2	0	55
12.002	0	0	7	12	0	0	0	0	0	0	4	0	0	0	0	8	0	0	3	0	2	1	37
.004	0	0	13	69	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	85
.006	0	0	6	22	0	0	0	1	0	0	3	0	0	0	0	0	0	0	0	0	1	0	33
.008	0	0	24	45	0	0	0	10	0	0	8	0	0	0	0	0	0	0	1	0	0	0	88
.010	0	0	18	73	0	0	0	22	0	0	4	0	0	0	0	0	0	0	0	0	0	4	121
.012	0	0	8	12	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31
.014	0	0	7	13	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	23
.016	0	0	20	38	0	0	0	4	0	0	7	0	0	0	0	0	0	0	0	0	0	0	69
.018	0	0	60	65	0	0	0	6	0	0	6	0	0	0	0	0	0	0	0	0	0	0	137
.020	0	0	8	60	0	0	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	74
.022	0	0	1	13	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	16
.024	0	0	24	72	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	97
.026	0	0	29	80	0	0	0	9	0	0	2	1	0	0	0	0	0	0	0	0	0	0	121
.028	0	0	6	1	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	2	1	13
.030	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	24
.032	0	0	10	6	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	20
.033	63	0	21	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	87
.035	0	0	14	6	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	23
.037	0	0	22	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	36
.039	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17
.041	0	0	107	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	108
.043	0	0	82	2	0	0	3	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	94
.045	0	0	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33
.047	0	0	48	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	61
.049	0	0	53	7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	61
.051	0	0	35	13	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	51
.053	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
.055	0	0	1	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
.057	0	0	2	32	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	37

PPENDIX TABLE 2.—Myctophid larvae, tabulated by genus or species, for all stations occupied on EASTROPAC I. —*Continued.*

STATION NUMBER	Benthosema panamense	Ceratoscopelus townsendi	Diaphus spp.	Diogenichthys laternatus	Diogenichthys atlanticus	Electrona sp.	Gonichthys tenuiculus	Hygophum atratum	Hygophum proximum	Lampadena spp.	Lampanyctus spp.	Lepidophanes pyrsobolus	Lobianchia sp.	Loweina rara	Myctophum spp.	Notolychnus valdiviae	Notoscopelus resplendens	Protomyctophum sp.	Symbolophorus evermanni	Triphoturus spp.	Unidentified myctophids	Disintegrated myctophids	Total myctophids
2.059	0	0	0	26	0	0	5	0	0	0	56	0	0	0	0	7	0	0	0	0	0	5	99
.061	0	0	0	32	0	0	1	0	0	0	5	0	0	0	0	2	0	0	1	0	0	0	41
.063	0	0	0	104	0	0	1	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0	109
.065	0	0	0	555	0	0	3	0	2	0	25	0	0	0	2	17	4	2	2	0	1	1	614
.067	0	0	4	337	0	0	0	0	0	0	17	1	0	0	0	4	0	0	0	0	0	3	366
.069	0	0	0	195	0	0	0	0	2	0	14	0	0	1	0	6	3	1	4	0	1	0	227
.071	0	0	2	25	0	1	0	0	0	0	15	0	2	0	6	11	0	4	0	0	2	3	71
.075	0	0	16	204	0	1	0	0	12	2	11	0	0	0	10	11	3	0	2	3	1	18	294
.077	0	0	6	65	0	0	0	0	7	0	1	0	0	2	4	10	6	0	0	3	0	6	110
.079	0	0	18	80	0	0	0	1	0	0	5	0	0	0	12	10	0	0	0	0	0	3	129
.081	0	3	7	103	0	0	0	0	9	0	37	0	0	0	11	16	2	7	1	0	0	193	389
.084	0	0	27	127	0	0	0	2	2	0	30	0	0	0	1	13	0	3	0	0	1	1	207
.087	0	0	3	38	0	0	0	0	0	0	12	1	0	1	2	2	0	0	0	1	4	0	64
.090	0	0	1	5	0	0	0	0	0	0	7	0	0	0	0	4	0	0	0	0	1	0	18
.092	0	0	0	12	0	0	0	2	12	0	20	0	0	0	6	0	13	0	0	0	5	1	71
.094	0	0	5	62	0	0	13	25	42	0	140	0	0	0	34	35	0	0	3	11	0	7	377
.097	0	0	0	36	0	0	0	3	3	0	27	0	0	0	9	0	3	0	0	0	0	20	101
2.100	0	0	4	33	0	0	1	0	0	0	5	0	0	0	3	0	2	1	0	1	4	2	56
.103	0	0	6	67	0	0	2	2	0	0	35	0	0	0	3	0	1	0	0	5	0	3	124
.106	0	0	10	277	0	0	0	0	0	0	25	0	0	0	0	0	0	1	0	4	2	0	319
.109	0	0	4	41	0	0	0	0	0	0	8	0	0	0	3	0	0	0	0	7	0	2	65
.112	0	0	1	25	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	3	32
.115	0	0	0	48	0	0	0	0	0	0	17	0	0	0	0	0	0	0	0	2	0	5	72
.118	0	0	12	7	0	0	1	4	0	0	54	0	0	0	2	6	0	0	20	1	0	0	107
.120	0	0	5	1	0	0	0	0	0	0	7	0	0	0	0	0	0	0	2	0	0	0	15
.122	0	8	14	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	6	0	0	0	30
.124	0	8	5	0	0	0	0	1	0	0	6	1	0	1	1	0	0	0	3	0	0	3	29
.126	0	28	19	0	0	0	0	2	2	1	14	0	0	0	3	0	0	0	39	0	0	0	108
.128	0	2	28	0	0	0	0	2	0	0	6	0	0	0	1	1	0	0	8	0	0	1	49
.130	0	5	2	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	2	0	0	0	12
.132	0	1	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0	1	0	8
.134	0	10	2	0	0	0	0	1	0	0	2	0	0	0	0	3	0	0	1	0	0	1	20
.136	0	6	3	0	1	0	1*	0	1	1	3	0	0	0	1	0	1	0	0	0	1	0	19
.138	0	0	1	1	0	0	0	0	1	0	2	0	0	0	2	1	0	0	1	0	0	1	10
.140	0	0	6	0	2	0	0	0	0	0	3	48	0	0	3	3	0	0	3	0	1	0	69
.142	0	19	11	0	2	7	0	1	5	0	4	3	0	0	3	5	2	0	7	9	0	6	84
.144	0	4	21	0	4	14	0	0	10	0	0	0	0	0	2	1	4	0	3	3	2	4	72
.146	0	0	2	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	11
.148	0	0	5	0	1	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	2	11
.150	0	0	47	0	0	0	0	1	0	9	13	11	0	0	0	0	1	0	0	0	0	5	86
.152	0	0	7	0	0	1	0	1	0	0	1	22	0	0	0	0	0	0	0	3	0	2	37
.154	0	3	0	0	0	4	0	0	0	2	1	0	0	0	0	0	0	0	1	0	1	0	12
.156	0	1	2	0	0	0	1*	0	1	0	4	2	0	0	1	0	0	0	0	0	2	0	14
.158	0	7	6	0	0	0	0	2	7	0	5	6	0	0	4	0	0	0	2	0	0	2	41
.160	0	0	1	0	0	0	0	0	5	2	2	3	0	0	2	0	0	0	0	0	0	4	19
.162	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	5
.164	0	11	7	0	0	0	0	1	3	0	6	0	0	0	1	1	0	0	2	0	3	1	36
.184	0	1	15	0	0	1	0	0	1	0	10	0	0	0	2	0	0	0	14	1	0	0	45
.186	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	5
.188	0	0	3	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	1	0	1	0	8

APPENDIX TABLE 2.—Myctophid larvae, tabulated by genus or species, for all stations occupied on EASTROPAC I. —*Continued.*

STATION NUMBER	Benthosema panamense	Ceratoscopelus townsendi	Diaphus spp.	Diogenichthys laternatus	Diogenichthys atlanticus	Electrona sp.	Gonichthys tenuiculus	Hygophum atratum	Hygophum proximum	Lampadena spp.	Lampanyctus spp.	Lepidophanes pyrsobolus	Lobianchia sp.	Loweina rara	Myctophum spp.	Notolychnus valdiviae	Notoscopelus resplendens	Protomyctophum sp.	Symbolophorus evermanni	Triphoturus spp.	Unidentified myctophids	Disintegrated myctophids	Total myctophids
12.190	0	0	2	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	2	0	0	0	6
.192	0	13	1	0	0	0	0	0	2	1	5	4	0	0	1	8	0	0	9	0	1	0	45
.194	0	1	0	0	0	0	0	0	0	0	8	3	0	0	1	1	0	0	1	0	0	1	16
.196	0	2	5	0	0	0	0	0	0	1	9	0	0	1	0	0	0	0	3	0	0	1	22
.198	0	1	1	0	0	0	0	0	0	0	2	0	0	0	0	5	0	0	2	0	1	0	12
12.200	0	0	0	1	0	0	0	1	1	0	13	0	0	0	0	5	0	1	12	0	1	1	36
.203	0	0	0	80	0	0	0	0	0	0	10	0	0	0	0	0	0	0	1	0	0	0	91
.206	0	0	0	10	0	0	0	0	0	0	21	0	0	0	0	0	0	1	0	0	1	3	36
.209	0	0	0	28	0	0	0	1	0	0	35	0	0	0	0	2	0	1	0	1	0	2	70
.212	0	0	13	92	0	0	0	0	0	0	176	0	0	0	1	6	0	5	0	1	0	6	300
.215	0	0	7	92	0	0	0	1	0	0	98	0	0	0	0	0	0	0	0	2	0	2	202
.218	0	0	4	22	0	0	11	4	2	0	61	0	0	0	6	0	12	0	0	0	2	3	127
.221	0	0	2	102	0	0	2	3	13	0	47	0	0	0	18	0	5	0	5	1	0	11	209
.224	0	0	5	315	0	0	5	63	39	0	471	0	1	0	105	6	30	0	6	5	0	38	1089
.227	0	1	6	98	0	0	1	5	4	0	30	0	0	0	10	0	2	0	0	0	1	4	162
.230	0	0	1	22	0	0	1	1	1	0	16	0	0	0	2	3	0	1	1	0	0	0	49
.233	0	0	3	126	0	0	1	0	0	0	107	0	0	2	2	4	0	1	0	1	2	1	250
.235	0	0	0	194	0	0	1	1	0	0	61	0	0	0	3	17	1	1	1	0	0	0	280
.238	0	0	2	145	0	0	0	1	0	0	42	0	0	3	16	11	4	0	1	0	0	0	225
.240	0	0	0	23	0	0	0	1	5	0	5	0	0	1	8	2	3	0	0	0	0	6	54
.242	0	0	0	14	0	0	0	0	3	0	1	0	0	0	1	2	0	1	0	2	1	0	25
.244	0	0	10	17	0	0	0	1	17	2	10	0	0	0	7	15	0	3	12	8	0	3	105
.246	0	0	7	205	0	0	1	0	0	0	16	0	0	0	0	2	2	0	2	4	3	6	248
.248	0	0	0	43	0	0	0	0	0	0	5	0	0	0	0	2	0	0	0	0	0	1	51
.250	0	0	6	38	0	0	1	0	0	0	6	0	0	0	0	2	0	0	0	0	0	1	54
.252	0	0	7	13	0	0	0	0	0	0	12	0	0	0	0	6	0	1	5	0	0	0	44
.254	0	0	9	22	0	0	0	0	0	0	16	0	0	0	0	1	0	1	35	0	0	0	84
.256	0	0	5	11	0	0	0	0	0	0	2	0	0	0	0	0	0	1	3	0	1	0	23
.258	0	0	0	38	0	0	1	0	0	0	1	0	0	0	0	2	0	0	1	0	0	0	43
.260	0	0	0	26	0	0	0	0	0	0	40	0	0	0	2	6	0	0	0	0	0	0	74
.262	0	0	127	24	0	0	0	1	0	0	2	0	0	0	0	0	0	0	7	0	0	0	161
.264	0	1	3	15	0	0	0	0	0	0	3	0	0	0	0	0	0	0	2	0	0	2	26
.265	0	0	17	31	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	4	54
.268	0	0	57	44	0	0	0	54	0	0	1	0	0	0	0	0	0	0	0	0	0	0	156
.270	0	0	12	35	0	0	1	11	0	0	0	0	0	0	0	0	0	0	0	0	0	1	60
.272	0	0	1	61	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	3	0	81
.274	0	1	17	25	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0	0	2	0	85
.276	0	0	7	8	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0	0	1	0	20
.278	0	0	6	19	0	0	0	13	0	0	7	0	0	0	0	0	0	0	0	0	0	0	45
.280	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5
.282	0	0	0	5	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	8
.284	0	0	0	10	0	0	0	3	0	1	2	0	0	0	0	0	0	0	0	0	0	0	16
13.001	0	0	0	31	0	0	0	0	0	0	6	0	0	0	0	0	1	0	0	1	2	0	41
.003	0	3	0	315	0	0	0	0	0	0	34	0	0	0	0	12	0	0	8	10	3	0	385
.005	0	0	0	1020	0	0	3	0	0	0	21	0	0	0	0	24	2	0	2	1	2	0	1075
.007	0	0	0	115	0	0	1	0	0	0	6	0	0	0	1	7	0	0	2	0	1	0	133
.009	0	0	0	470	0	0	0	0	0	0	21	0	0	0	0	0	1	0	0	0	2	0	494
.011	0	0	0	372	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	374

PPENDIX TABLE 2.—Myctophid larvae, tabulated by genus or species, for all stations occupied on EASTROPAC I. —*Continued.*

STATION NUMBER	Benthosema panamense	Ceratoscopelus townsendi	Diaphus spp.	Diogenichthys laternatus	Diogenichthys atlanticus	Electrona sp.	Gonichthys tenuiculus	Hygophum atratum	Hygophum proximum	Lampadena spp.	Lampanyctus spp.	Lepidophanes pyrsobolus	Lobianchia sp.	Loweina rara	Myctophum spp.	Notolychnus valdiviae	Notoscopelus resplendens	Protomyctophum sp.	Symbolophorus evermanni	Triphoturus spp.	Unidentified myctophids	Disintegrated myctophids	Total myctophids
3.013	0	0	0	186	0	0	1	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	207
.015	0	0	0	477	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	479
.017	0	0	0	550	0	0	2	0	0	0	5	0	0	0	0	1	0	0	1	0	0	0	559
.019	482	0	0	715	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	13	1219
.021	407	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	409
.022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.028	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
.030	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24
.032	0	0	0	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44
.034	0	0	0	142	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	158
.036	0	0	0	11	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	13
.038	0	0	0	122	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0	2	142
.040	0	0	0	408	0	0	3	0	0	0	47	0	0	0	0	1	1	6	1	0	0	2	469
.042	0	0	0	271	0	0	0	0	0	0	25	0	0	1	0	3	0	6	0	0	0	1	307
.044	0	0	0	79	0	0	0	0	1	0	14	0	0	0	2	7	1	3	1	0	1	0	109
.046	0	0	0	44	0	0	1	0	0	0	28	0	1	0	2	8	0	3	7	1	4	6	105
.048	0	0	1	160	0	0	4	0	3	0	76	3	2	0	5	19	0	4	9	10	2	2	300
.050	0	0	1	71	0	0	2	0	1	0	25	7	1	0	2	11	1	2	4	4	1	0	133
.052	0	0	0	42	0	0	0	0	0	0	14	0	1	1	1	5	0	0	4	4	5	2	79
.054	0	0	0	36	0	0	1	0	0	0	20	0	3	0	0	12	0	0	2	0	3	0	77
.056	0	0	3	33	0	0	0	0	8	0	43	0	2	1	5	8	0	0	4	12	21	4	144
.058	0	0	2	50	0	0	3	0	0	0	16	0	0	1	0	1	0	0	0	5	5	0	83
.060	0	0	0	54	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	2	59
.062	0	0	4	22	0	0	1	3	0	0	7	0	0	0	0	0	1	0	0	3	2	1	44
.064	0	0	5	191	0	0	15	2	1	0	18	0	0	0	6	1	21	1	0	10	3	0	274
.065	0	0	1	12	0	0	2	1	1	0	8	0	0	0	1	0	1	1	0	1	0	2	31
.067	0	0	2	24	0	0	2	0	0	0	2	0	0	0	0	0	3	0	0	0	0	1	34
.069	0	0	2	73	0	0	2	0	0	0	10	0	0	1	0	0	5	0	0	2	1	3	99
.071	0	0	0	284	0	0	6	0	0	0	20	0	0	0	0	0	0	0	2	5	0	1	318
.073	0	0	0	122	0	0	3	0	0	0	40	0	0	0	0	0	0	0	2	5	0	0	172
.075	0	0	0	28	0	0	2	0	0	0	5	0	0	0	0	0	0	0	1	0	0	3	39
.077	0	0	0	60	0	0	1	0	0	0	23	0	0	0	0	0	0	0	1	3	0	1	89
.079	0	0	0	50	0	0	1	0	0	0	8	0	0	0	0	1	0	0	7	2	0	0	69
.081	0	0	0	11	0	0	0	0	0	0	3	0	0	0	0	0	0	0	1	1	0	0	16
.083	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	17
.085	0	0	0	9	0	0	0	0	0	0	2	0	0	0	0	0	0	0	6	0	0	0	17
.087	0	9	0	0	0	0	0	3	0	0	0	0	0	0	0	4	0	0	18	0	1	2	37
.089	0	25	1	0	0	0	0	2	0	0	3	0	0	0	0	7	0	0	34	0	32	1	105
.091	0	13	12	0	0	0	0	10	0	0	0	0	0	0	1	1	0	0	8	0	0	4	49
.093	0	0	1	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	2	0	0	2	8
.095	0	45	11	1	2*	0	0	45	3	0	7	0	0	1	15	21	4	0	30	3	3	4	195
.097	0	20	21	0	18	2	1	33	4	0	3	1	4	0	18	37	7	0	24	6	5	1	205
.099	0	15	4	0	2	0	0	5	2	0	1	0	0	0	0	7	0	0	5	6	1	0	48
.101	0	6	10	0	1	0	0	6	0	0	0	0	0	0	3	4	0	0	10	5	0	0	45
.103	0	29	46	9	12*	3	0	42	9	0	19	0	4	0	11	16	13	0	26	6	10	0	255
.105	0	30	19	0	6	3	0	22	3	0	5	0	0	0	5	7	0	0	33	24	4	5	166
.107	0	2	1	0	0	0	0	2	1	0	1	0	0	0	2	0	0	0	1	0	2	1	13
.109	0	1	15	0	0	1	0	2	2	0	1	0	0	0	0	1	0	0	1	1	1	1	27
.111	0	6	17	0	0	1	0	5	0	0	3	1	1	0	7	2	1	0	0	4	0	1	49
.113	0	17	26	0	4	1	0	1	0	7	5	1	0	0	1	1	0	0	2	2	2	2	72

APPENDIX TABLE 2.—Myctophid larvae, tabulated by genus or species, for all stations occupied on EASTROPAC I. —*Continued.*

STATION NUMBER	Benthosema panamense	Ceratoscopelus townsendi	Diaphus spp.	Diogenichthys laternatus	Diogenichthys atlanticus	Electrona sp.	Gonichthys tenuiculus	Hygophum atratum	Hygophum proximum	Lampadena spp.	Lampanyctus spp.	Lepidophanes pyrsobolus	Lobianchia sp.	Loweina rara	Myctophum spp.	Notolychnus valdiviae	Notoscopelus resplendens	Protomyctophum sp.	Symbolophorus evermanni	Triphoturus spp.	Unidentified myctophids	Disintegrated myctophids	Total myctophids
13.115	0	2	4	0	4	2	1*	0	0	2	0	0	0	0	3	1	0	0	0	0	4	2	25
.117	0	2	20	0	0	0	0	0	0	18	7	0	0	1	1	0	0	0	0	0	3	0	52
.119	0	7	56	0	0	2	0	3	0	6	3	1	0	0	0	0	0	0	0	4	4	0	86
.121	0	6	1	0	0	1	1*	4	0	1	2	0	0	0	1	2	0	0	0	0	2	1	22
.123	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3
.125	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	2
.127	0	7	3	0	0	3	2*	4	4	3	5	0	1	0	1	4	0	0	0	0	2	0	39
.129	0	7	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	1	0	2	0	14
.131	0	2	1	0	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	7
.133	0	2	1	0	0	0	0	0	0	2	1	0	0	0	1	0	0	0	0	0	0	2	9
.135	0	12	35	0	0	1	1*	0	1	11	7	0	1	0	0	0	0	0	0	5	2	2	78
.137	0	5	13	0	0	3	0	2	0	2	6	0	0	0	2	6	0	0	0	9	0	2	50
.139	0	0	3	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	2	8
.141	0	1	0	0	1	0	0	0	0	0	1	0	0	0	3	1	0	0	0	0	0	1	8
.143	0	15	21	0	6	2	0	4	0	5	7	2	0	0	5	1	0	0	1	13	2	2	86
.145	0	16	6	0	4	0	0	2	0	0	4	0	0	0	0	2	2	0	0	8	0	0	44
.147	0	2	5	0	2	2	0	0	0	0	2	0	0	0	3	2	3	0	1	10	0	1	33
.149	0	2	2	0	2	0	0	1	0	0	1	2	0	0	3	5	0	0	5	3	1	2	29
.151	0	43	6	0	2	0	0	0	0	4	0	3	0	0	2	1	0	0	1	8	1	1	72
.153	0	83	172	0	7	0	0	30	23	0	9	0	0	0	7	26	1	0	11	8	3	14	394
.155	0	4	2	0	0	2	0	0	0	0	0	0	0	0	0	4	0	0	4	0	0	0	16
.157	0	11	19	0	1	1	0	4	0	0	0	0	0	0	0	2	0	0	1	2	0	4	45
.159	0	12	16	0	0	0	0	3	0	0	1	0	0	0	0	7	0	0	7	0	2	5	53
.161	0	27	11	0	1	0	0	4	1	0	4	0	0	0	0	4	0	0	10	0	1	2	65
.163	0	1	2	0	0	0	0	0	0	0	3	0	0	0	0	1	0	0	6	0	0	1	14
.165	0	3	6	0	0	0	0	0	0	0	0	0	1	0	2	3	0	0	8	0	0	1	24
.167	0	16	2	0	0	0	0	2	0	0	3	0	0	0	1	0	0	0	8	0	1	0	33
.169	0	115	1	8	0	0	0	2	0	0	20	1	0	0	0	1	0	0	17	0	0	4	169
.171	0	5	13	54	0	0	1	0	0	0	7	0	0	0	0	2	0	0	8	0	3	11	104
.173	0	2	0	98	0	0	0	0	0	0	13	0	0	1	0	0	0	0	2	0	1	4	121
.175	0	0	1	168	0	0	0	1	0	0	52	0	0	1	2	0	0	0	18	0	2	0	245
.179	0	0	0	122	0	0	1	0	0	0	7	0	0	0	2	0	0	0	0	1	0	0	133
.183	0	0	0	64	0	0	3	0	0	0	7	0	0	1	2	0	0	0	0	2	0	1	80
.187	0	0	0	49	0	0	2	0	0	0	11	0	0	0	0	0	1	0	0	3	0	1	67
.191	0	0	0	78	0	0	2	0	0	0	43	0	0	0	0	0	0	0	0	3	0	0	126
.195	0	0	4	34	0	0	0	0	0	0	125	0	0	2	0	0	0	0	1	16	0	0	182
.199	0	0	1	31	0	0	4	2	0	0	12	0	0	0	3	0	2	0	0	0	0	0	55
13.203	0	0	0	7	0	0	1	3	0	0	3	0	0	0	4	0	0	0	1	0	0	1	20
.207	0	0	1	72	0	0	12	8	1	0	24	0	0	1	2	1	0	0	0	4	0	3	129
.211	0	0	3	40	0	0	5	1	0	0	9	0	0	0	3	1	0	0	0	2	4	0	68
.215	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	7
.219	0	0	0	6	0	0	1	0	0	0	3	0	0	0	1	0	0	0	0	0	0	0	11
.223	0	0	0	18	0	1	0	0	0	0	9	0	0	0	0	1	0	0	0	2	1	0	32
.227	0	0	2	90	0	0	1	0	3	0	15	0	0	0	0	2	0	0	1	1	6	0	121
.231	0	0	0	29	0	0	2	0	0	0	39	0	0	0	4	3	1	0	0	0	2	2	82
.235	0	0	1	64	0	1	3	0	0	0	14	0	0	1	5	7	0	3	0	1	1	5	106
.237	0	0	0	133	0	0	0	0	0	4	34	0	0	0	0	8	0	1	1	2	1	5	189
.239	0	0	0	131	0	0	1	0	0	0	29	0	0	0	0	7	0	4	2	5	0	0	179
.241	0	0	0	52	0	0	0	0	0	1	1	0	0	0	1	1	0	1	0	0	0	2	59
.243	0	0	0	67	0	0	0	0	0	1	21	0	0	0	0	0	0	0	0	1	0	3	93

PENDIX TABLE 2.—Myctophid larvae, tabulated by genus or species, for all stations occupied on EASTROPAC I. —*Continued.*

STATION NUMBER	Benthosema panamense	Ceratoscopelus townsendi	Diaphus spp.	Diogenichthys laternatus	Diogenichthys atlanticus	Electrona sp.	Gonichthys tenuiculus	Hygophum atratum	Hygophum proximum	Lampadena spp.	Lampanyctus spp.	Lepidophanes pyrsobolus	Lobianchia sp.	Loweina rara	Myctophum spp.	Notolychnus valdiviae	Notoscopelus resplendens	Protomyctophum sp.	Symbolophorus evermanni	Triphoturus spp.	Unidentified myctophids	Disintegrated myctophids	Total myctophids
245	0	0	0	37	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	57
247	0	0	0	17	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	26
249	0	0	0	43	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	46
251	0	0	0	15	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	25
253	0	0	0	5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	6
255	12	0	11	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	2	0	29
257	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1	10
259	0	0	16	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	4	23
261	0	0	8	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	13
263	0	0	33	5	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	46
265	0	0	11	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	14
266	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
268	0	0	12	19	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33
270	0	0	5	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	9
272	0	0	11	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	13
274	0	0	26	33	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	63
276	0	0	38	48	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	89
278	0	0	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	7
280	0	0	23	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	31
282	0	0	80	7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	89
284	0	0	13	7	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	1	0	34
318	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
320	3	0	11	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18
322	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
324	0	0	0	25	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26
326	0	0	5	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44
328	0	0	0	28	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	35
330	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24
332	0	0	0	62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	63
334	0	0	0	111	0	0	1	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	116
338	0	0	0	274	0	0	0	0	0	0	15	0	0	0	0	1	0	1	0	2	1	1	295
340	0	0	0	33	0	0	0	0	0	0	5	0	0	0	3	3	0	1	0	1	1	0	47
342	0	0	0	62	0	0	0	0	0	0	6	0	0	0	2	3	0	0	0	1	1	1	76
001	46	0	0	725	0	0	1	0	0	0	49	0	0	0	18	0	0	0	5	17	0	6	867
006	0	0	9	43	0	0	0	0	0	0	3	0	0	0	1	0	0	0	0	2	8	0	66
008	0	0	0	78	0	0	0	0	0	0	3	0	0	0	5	0	0	0	0	0	0	0	86
010	0	0	6	179	0	0	0	2	0	0	4	0	0	0	6	0	0	0	0	0	0	1	198
012	0	0	0	47	0	0	0	0	0	0	2	0	0	0	7	0	0	0	0	0	0	1	57
014	0	0	1	65	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	67
016	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
017	0	0	0	54	0	0	1	0	0	0	1	0	0	0	4	0	0	0	0	0	0	1	61
018	0	0	0	246	0	0	1	0	0	0	148	0	0	0	23	0	0	0	4	1	0	1	424
020	0	0	0	225	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	1	0	229
022	0	0	1	73	0	0	0	0	0	0	3	0	0	0	2	0	0	0	1	0	0	0	80
024	0	0	0	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	47
027	0	0	0	372	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	4	387
029	0	0	5	371	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	382
031	0	0	4	540	0	0	1	1	0	0	19	0	0	0	13	0	0	0	6	2	1	7	594

APPENDIX TABLE 2.—Myctophid larvae, tabulated by genus or species, for all stations occupied on EASTROPAC I. —*Continued.*

STATION NUMBER	Benthosema panamense	Ceratoscopelus townsendi	Diaphus spp.	Diogenichthys laternatus	Diogenichthys atlanticus	Electrona sp.	Gonichthys tenuiculus	Hygophum atratum	Hygophum proximum	Lampadena spp.	Lampanyctus spp.	Lepidophanes pyrsobolus	Lobianchia sp.	Loweina rara	Myctophum spp.	Notolychnus valdiviae	Notoscopelus resplendens	Protomyctophum sp.	Symbolophorus evermanni	Triphoturus spp.	Unidentified myctophids	Disintegrated myctophids	Total myctophids
14.033	0	0	0	21	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	2	26
.040	0	0	1	16	0	0	4	0	0	0	5	0	0	0	9	0	0	0	0	1	0	0	36
.043	0	0	4	25	0	0	9	0	0	0	40	0	0	0	41	0	25	0	2	3	1	9	159
.047	0	0	0	9	0	0	0	0	0	0	4	0	0	0	8	0	0	0	0	1	0	0	22
.051	0	0	0	31	0	0	0	0	0	0	27	0	0	0	12	0	0	0	1	1	0	6	78
.055	0	0	0	37	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	40
.060	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	18
.066	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.069	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.076	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.078	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.081	0	0	0	5	0	0	0	0	0	0	8	0	0	0	0	0	0	0	3	1	0	1	18
.084	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
.086	0	0	0	1	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	1	7
.088	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
.091	0	1	0	0	0	0	0	0	0	0	40	0	0	0	0	0	0	0	1	1	0	0	43
.095	0	0	0	17	0	0	0	0	0	0	1	0	0	0	0	0	1	0	19	0	0	12	50
.099	0	0	0	7	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	1	15
14.103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.106	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.110	0	0	0	6	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	1	0	6	27
.112	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2
.114	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2
.115	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	1	0	0	0	5
.117	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
.118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.120	0	0	1	5	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	4	2	0	15
.122	0	0	0	7	0	0	0	0	0	0	1	0	0	0	0	0	1	0	8	1	0	1	19
.123	0	0	0	7	1	0	1	6	0	0	4	1	0	0	0	1	0	0	16	1	0	13	51
.124	0	6	4	15	1	0	0	40	0	0	18	0	0	1	2	1	2	0	51	1	10	0	152
.126	0	1	3	0	0	0	0	5	0	0	1	0	0	0	5	3	0	0	21	1	0	13	53
.127	0	1	1	0	0	0	1	2	0	0	1	0	0	0	1	0	0	0	5	9	0	1	22
.128	0	3	10	2	0	0	0	33	0	0	5	2	0	0	0	4	3	0	72	9	2	0	145
.130	0	0	1	7	0	0	0	1	0	0	0	3	0	0	5	2	0	0	21	0	0	5	45
.131	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
.132	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	3	1	0	1	8
.134	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	11
.136	0	0	0	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43
.138	0	0	0	15	0	0	1	0	0	0	11	0	0	0	0	0	0	0	0	2	0	0	29
.142	0	0	0	108	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	110
.146	0	0	0	152	0	0	5	0	0	0	13	0	0	0	0	0	0	0	0	6	0	0	176
.150	0	0	0	39	0	0	0	0	0	0	6	0	0	0	0	0	0	0	2	0	0	5	52
.154	0	0	2	12	0	0	0	0	0	0	49	0	0	0	16	0	0	0	8	2	3	0	92
.158	0	0	0	17	0	0	0	0	0	0	7	0	0	0	2	0	0	0	0	0	0	4	30
.164	0	0	0	76	0	0	1	0	0	0	30	0	0	0	5	0	1	0	0	2	0	20	135
.172	0	0	0	16	0	0	2	0	0	0	6	0	0	0	0	0	1	0	0	1	0	0	26
.174	0	0	4	11	0	0	1	0	0	0	4	0	0	0	2	3	0	0	1	0	0	0	26
.177	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.183	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	4
.188	0	0	0	181	0	0	3	0	0	0	49	0	0	0	6	2	9	0	5	6	0	0	261

APPENDIX TABLE 2.—Myctophid larvae, tabulated by genus or species, for all stations occupied on EASTROPAC I. —*Continued.*

STATION NUMBER	Benthosema panamense	Ceratoscopelus townsendi	Diaphus spp.	Diogenichthys laternatus	Diogenichthys atlanticus	Electrona sp.	Gonichthys tenuiculus	Hygophum atratum	Hygophum proximum	Lampadena spp.	Lampanyctus spp.	Lepidophanes pyrsobolus	Lobianchia sp.	Loweina rara	Myctophum spp.	Notolychnus valdiviae	Notoscopelus resplendens	Protomyctophum sp.	Symbolophorus evermanni	Triphoturus spp.	Unidentified myctophids	Disintegrated myctophids	Total myctophids
14.194	0	0	0	1551	0	0	7	0	0	0	158	0	0	2	12	4	8	0	5	5	1	0	1753
.195	0	0	0	243	0	0	2	0	0	0	0	0	0	0	3	0	0	0	0	0	0	4	252
.199	0	0	1	10	0	0	0	0	0	0	2	0	0	0	0	1	0	0	2	0	0	0	16
14.203	0	0	0	90	0	0	1	0	0	0	65	0	0	0	3	1	3	0	4	4	1	7	179
.209	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	25
.213	0	0	0	181	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	206
.218	0	0	0	168	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	1	0	0	177
.220	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	22
.220	0	0	0	46	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	49
.224	0	0	0	90	0	0	0	0	0	0	21	0	0	0	0	0	0	0	2	0	0	2	115
.228	0	0	0	28	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	30
.230	0	0	0	39	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	41
.232	0	0	0	21	0	0	0	0	0	0	9	0	0	0	0	0	0,	0	0	1	0	0	31
.234	0	0	0	98	0	0	0	0	0	0	81	0	0	0	0	0	0	0	0	0	1	48	228
.236	0	0	0	30	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	34
.240	0	0	0	70	0	0	4	0	0	0	12	0	0	1	20	2	2	0	1	1	0	3	116
.243	0	0	0	23	0	0	2	0	0	0	14	0	0	0	2	0	2	0	0	0	0	1	44
.247	0	0	0	41	0	0	3	0	0	0	27	0	0	0	5	0	2	0	1	6	0	1	86
.251	0	0	0	19	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0	1	1	0	25
.255	0	0	1	216	0	0	1	0	0	0	2	0	0	0	3	0	0	0	0	3	1	0	227
.259	0	0	0	46	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	3	1	53
.263	0	0	0	94	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	1	0	0	105
.267	0	0	0	4	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	1	0	8
.276	0	0	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	6	0	2	1	13
.280	0	0	0	6	0	0	2	0	0	0	2	0	0	0	0	0	0	0	26	3	0	5	44
.283	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	1	1	0	22
.287	0	0	0	3	0	0	0	0	0	0	4	0	0	0	0	0	0	0	1	2	4	1	15
.291	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.295	0	0	0	49	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	1	0	65
.300	0	0	0	16	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	18
.303	0	0	0	189	0	0	0	0	0	0	5	0	0	0	3	0	0	0	0	3	0	0	200
.306	0	0	0	27	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	4	0	0	32
.310	0	0	1	61	0	0	2	0	0	0	8	0	0	1	5	0	4	0	0	14	0	0	96
.314	0	0	0	38	0	0	0	0	0	0	14	0	0	0	5	0	0	0	0	0	2	0	59
.318	0	0	0	491	0	0	7	0	0	0	38	0	0	0	23	0	5	0	0	2	0	0	566
.323	0	0	8	149	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	3	3	165
.326	0	0	3	573	0	0	0	0	0	0	73	0	0	0	1	0	0	0	0	4	0	5	659
.330	0	0	0	22	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	23

APPENDIX TABLE 3.—Counts of selected categories of fish larvae, tabulated by station, EASTROPAC I.

STATION NUMBER	Bathylagus nigrigenys	Leuroglossus stilbius urotranus	Nansenia spp.	Araiophos sp.	Cyclothone spp.	Diplophos sp.	Ichthyococcus spp.	Maurolicus muelleri	Vinciguerria spp.	Bathophilus filifer	Evermannellidae	Macroparalepis macrurus	Sudis atrox	Scopelosaurus spp.	Oxyporhamphus micropterus	Trachypteridae	Auxis spp.	Katsuwonis pelamis	Coryphaena spp.	Naucrates ductor	Howella pammelas	Tetragonurus sp.	Cerationdei
11.022	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.025	0	0	0	0	6	0	0	0	46	0	0	1	0	0	0	0	0	0	0	0	0	0	0
.027	0	0	0	0	2	0	0	0	34	0	1	1	0	0	0	0	0	0	0	0	0	0	0
.030	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.032	1	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.034	1	0	0	0	0	0	0	0	88	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.036	0	0	0	0	0	0	0	0	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.038	4	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.040	0	0	0	0	1	1	0	0	18	0	0	0	0	0	0	1	0	0	0	0	0	0	1
.044	2	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.046	3	0	0	0	1	0	0	0	57	0	0	0	0	0	0	1	0	0	0	0	0	0	0
.048	12	0	0	0	0	0	0	0	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.050	24	0	0	0	1	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.052	15	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.054	11	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.056	10	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.058	10	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0
.060	13	0	0	0	1	0	1	0	7	0	0	1	0	0	0	0	3	0	1	0	0	0	0
.062	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.064	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
.066	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2	0	2	1	1	0	11	0	1
.068	5	0	0	0	6	1	0	0	70	0	0	1	0	0	0	0	0	0	3	0	3	0	4
.070	1	0	0	0	6	1	0	0	17	0	3	1	0	0	1	0	0	0	0	0	8	0	1
.072	2	0	2	0	6	2	0	0	65	0	0	0	0	0	0	0	0	0	1	0	9	0	1
.076	6	0	0	0	5	0	2	0	682	1	1	0	0	0	0	0	0	4	0	0	0	0	0
.080	7	0	0	0	2	1	0	0	139	3	0	1	0	0	0	0	0	0	0	0	0	0	0
.084	11	0	0	0	3	0	0	0	358	0	0	0	0	0	0	0	3	0	0	0	2	0	0
.088	1	0	0	0	9	0	0	0	315	1	0	1	0	0	0	0	0	1	0	0	1	0	2
.094	0	0	0	0	9	0	0	0	41	0	0	0	0	0	0	1	0	0	1	0	1	0	2
.098	2	0	0	0	20	0	0	0	87	0	0	0	0	0	0	0	0	1	0	0	0	0	1
11.102	6	0	3	0	8	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	2	0	0
.106	1	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	4	0	2
.110	8	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.114	1	0	0	0	11	2	0	0	44	0	0	0	0	0	0	0	0	0	0	0	3	0	1
.118	4	0	0	0	1	2	0	0	4	0	0	0	0	0	0	0	0	0	0	0	2	0	0
.120	1	0	0	0	2	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1
.124	0	0	0	0	7	1	0	0	17	0	0	0	0	0	0	0	1	0	0	0	0	0	0
.128	0	0	0	0	6	0	0	0	92	0	0	0	0	0	0	0	0	0	0	0	2	0	1
.130	0	0	0	0	6	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.132	0	0	0	0	5	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0
.134	0	0	0	0	3	24	0	0	1	0	0	0	0	0	0	1	0	166	0	0	0	2	0
.136	0	0	0	0	24	2	0	0	20	0	0	0	0	0	0	0	0	2	0	0	0	0	0
.138	0	0	1	0	6	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.140	0	0	0	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.142	0	0	0	0	9	0	0	0	4	0	0	0	0	1	0	0	0	0	0	0	0	0	0
.146	0	0	0	20	2	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
.148	0	0	0	61	15	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.150	0	0	0	70	11	0	0	0	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0
.152	0	0	0	89	38	1	0	0	9	0	0	0	1	0	0	0	0	1	1	0	2	1	0
.154	0	0	2	5	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
.156	0	0	0	83	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.158	0	0	0	20	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
.159	0	0	0	70	24	0	0	0	6	0	0	0	3	0	0	0	0	0	0	0	0	0	0
.161	0	0	0	0	10	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1

PPENDIX TABLE 3.—Counts of selected categories of fish larvae, tabulated by station, EASTROPAC I.—*Continued.*

STATION NUMBER	Bathylagus nigrigenys	Leuroglossus stilbius urotranus	Nansenia spp.	Araiophos sp.	Cyclothone spp.	Diplophos sp.	Ichthyococcus spp.	Maurolicus muelleri	Vinciguerria spp.	Bathophilus filifer	Evermannellidae	Macroparalepis macrurus	Sudis atrox	Scopelo saurus spp.	Oxyporhamphus micropterus	Trachypteridae	Auxis spp.	Katsuwonis pelamis	Coryphaena spp.	Naucrates ductor	Howella pammelas	Tetragonurus sp.	Cerratioidei
11.163	0	0	0	0	8	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
.167	0	0	0	0	25	0	0	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0
.169	0	0	0	0	3	0	0	0	1	0	0	0	1	0	?	0	0	0	0	0	0	0	0
.171	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.173	0	0	0	0	9	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
.175	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.177	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.179	0	0	0	0	4	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
.181	0	0	0	0	13	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
.183	0	0	0	0	3	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.185	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.187	0	0	0	0	19	0	0	0	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0
.189	0	0	0	0	20	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.191	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.195	0	0	0	4	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.197	0	0	0	8	32	0	0	0	5	0	2	0	1	0	0	0	1	1	0	0	3	0	0
.199	0	0	0	5	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
11.201	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
.203	0	0	0	8	12	0	0	0	3	0	2	1	0	0	0	0	0	0	0	0	0	0	0
.205	0	0	0	22	20	0	2	0	9	3	0	0	0	0	0	0	0	0	0	0	0	0	0
.207	0	0	0	10	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
.209	0	0	0	3	3	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
.211	0	0	0	35	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
.213	0	0	0	13	10	1	0	0	12	0	0	0	0	0	0	0	1	3	0	0	1	0	0
.215	0	0	0	3	2	0	0	0	0	0	1	0	0	0	0	0	0	3	0	0	1	0	0
.217	0	0	0	0	3	0	0	0	5	0	0	0	0	0	0	1	0	0	0	0	0	0	1
.219	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.221	0	0	0	0	18	2	0	0	36	0	0	0	0	0	0	0	1	0	1	0	0	0	0
.223	0	0	0	0	8	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.226	0	0	0	0	2	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.228	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0
.234	2	0	0	0	7	2	0	0	8	0	0	0	0	0	0	1	0	0	2	0	1	1	1
.238	0	0	0	0	3	0	0	0	5	0	0	0	0	0	0	0	0	0	1	0	0	0	0
.242	4	0	0	0	13	0	1	0	36	0	0	0	0	0	0	0	0	0	0	0	4	0	0
.246	2	0	0	0	15	0	0	0	36	0	0	0	0	0	0	0	0	0	1	0	1	0	1
.250	1	0	1	0	12	0	0	0	8	0	0	0	0	0	0	1	0	0	1	0	0	0	1
.254	0	0	0	0	5	0	0	0	15	1	0	1	0	0	1	0	0	0	0	0	2	0	0
.258	3	0	1	0	8	0	0	0	46	0	0	0	0	0	0	0	0	0	0	0	1	0	0
.262	2	0	0	0	10	0	0	0	58	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.266	3	0	0	0	3	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.270	4	0	0	0	1	0	0	0	17	0	0	0	0	0	0	0	7	0	0	0	1	0	0
.278	13	0	1	0	13	0	0	0	142	0	0	0	0	0	0	0	0	0	1	0	0	0	0
.282	1	0	0	0	6	0	1	0	20	0	1	0	0	0	0	0	0	0	1	0	0	0	0
.285	9	0	0	0	5	0	0	0	5	0	2	1	0	0	1	0	0	0	1	0	1	0	1
.287	1	0	0	0	4	0	0	0	14	0	1	2	0	0	0	0	0	0	0	0	2	0	2
.289	0	0	0	0	7	4	0	0	5	0	0	0	0	0	0	0	0	0	1	0	18	0	6
.291	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	4	0	0
.293	7	0	1	0	1	0	0	0	2	0	0	0	0	0	0	0	6	0	0	0	14	0	1
.295	10	0	0	0	5	0	0	0	10	0	0	0	0	0	0	1	0	1	1	0	3	0	2
.297	5	0	0	0	3	0	0	0	9	0	0	0	0	0	0	0	2	1	0	0	1	0	4
.299	27	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	5	0	1	0	1	0	1
11.301	1	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	1	0	1	0	0	0	3
.303	12	0	0	0	2	0	0	0	45	0	0	0	0	0	0	1	0	0	0	0	0	0	1
.306	4	0	0	0	0	0	0	0	64	0	0	0	0	0	0	0	1	0	0	0	0	0	1

APPENDIX TABLE 3.—Counts of selected categories of fish larvae, tabulated by station, EASTROPAC I.—*Continued.*

STATION NUMBER	Bathylagus nigrigenys	Leuroglossus stilbius urotranus	Nansenia spp.	Araiophos sp.	Cyclothone spp.	Diplophos sp.	Ichthyococcus spp.	Maurolicus muelleri	Vinciguerria spp.	Bathophilus filifer	Evermannellidae	Macroparalepis macrurus	Sudis atrox	Scopelo saurus spp.	Oxyporhamphus micropterus	Trachypteridae	Auxis spp.	Katsuwonis pelamis	Coryphaena spp.	Naucrates ductor	Howella pammelas	Tetragonurus sp.	Ceratioidei
11.308	1	0	0	0	2	0	0	0	4	0	0	0	0	0	0	0	0	0	2	0	0	0	1
.310	4	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.312	0	0	0	0	2	1	0	0	59	0	0	1	0	0	0	1	0	0	0	0	0	0	1
.314	5	0	0	0	0	0	0	0	32	1	0	0	0	0	0	0	0	0	1	0	0	0	0
.316	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	1	0	0	0	0	0	0	0
.318	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.320	1	0	0	0	0	0	0	0	10	0	0	0	0	0	0	1	0	0	0	0	0	0	0
.322	0	0	0	0	2	0	0	0	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.324	0	0	0	0	2	0	0	0	19	0	0	1	0	0	0	0	0	0	0	0	0	0	0
.326	0	0	0	0	0	0	0	0	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.328	0	0	0	0	9	0	0	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.002	3	0	0	0	1	1	0	0	11	1	0	0	0	0	0	0	0	0	0	0	0	0	0
.004	3	0	0	0	0	1	0	0	11	3	0	0	0	0	0	0	0	0	0	0	0	0	0
.006	2	0	0	0	0	3	0	0	12	5	0	0	0	0	0	0	0	0	2	0	0	0	0
.008	3	0	0	0	0	6	0	0	59	2	0	0	0	0	0	0	0	0	1	0	0	0	0
.010	8	0	0	0	0	1	0	0	97	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.012	4	0	0	0	0	8	0	0	16	1	0	0	0	0	0	0	0	0	1	0	0	0	0
.014	4	0	0	0	0	5	0	0	33	2	0	0	0	0	0	0	0	0	0	0	0	0	0
.016	8	0	0	0	0	4	0	0	178	4	0	0	0	0	0	1	0	0	0	0	0	0	2
.018	0	0	0	0	0	0	0	0	199	7	0	0	0	0	1	0	0	0	0	0	0	0	0
.020	3	0	0	0	0	3	0	0	20	4	0	0	0	0	0	0	0	0	1	0	0	0	0
.022	0	0	0	0	0	4	0	0	11	1	0	0	0	0	1	0	0	0	0	0	0	0	0
.024	3	0	0	0	0	8	0	0	234	32	0	0	0	0	0	0	0	0	0	1	0	0	0
.026	4	0	0	0	0	2	0	0	99	3	0	0	0	0	0	0	0	0	0	0	0	0	0
.028	0	0	0	0	0	1	0	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.030	6	0	0	0	0	0	0	0	12	0	0	0	0	0	2	0	3	0	0	0	0	0	1
.032	0	0	0	0	0	0	0	0	13	1	0	0	0	0	0	0	1	0	0	0	0	0	3
.033	3	0	0	0	0	0	0	0	36	3	0	0	0	0	0	0	7	0	0	0	0	0	3
.035	1	0	0	0	0	1	0	0	72	4	0	0	0	0	0	0	6	0	1	0	0	0	0
.037	9	0	0	0	0	1	0	0	10	1	0	0	0	0	5	0	2	0	0	0	0	0	2
.039	4	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	2	0	0	0	0	0	0
.041	3	0	0	0	0	2	0	0	20	3	0	0	0	0	3	0	0	0	0	0	0	0	0
.043	0	0	0	0	0	0	0	0	28	2	0	0	0	0	3	0	1	0	0	0	0	0	0
.045	0	0	0	0	0	0	0	0	7	0	0	0	0	0	3	1	0	0	0	0	0	0	0
.047	1	0	0	0	0	2	0	0	2	0	0	0	0	0	3	0	0	0	0	0	0	0	0
.049	2	0	0	0	0	2	0	0	52	1	0	0	0	0	3	0	1	0	0	0	0	0	1
.051	0	0	0	0	0	0	0	0	68	0	0	0	0	0	0	0	2	0	0	0	0	0	0
.053	1	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.055	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	2	0	1	0	0	0	0
.057	2	0	0	0	0	0	0	0	13	0	0	0	0	0	0	2	0	0	0	0	0	0	0
.059	21	0	0	0	12	0	0	0	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.061	8	0	0	0	0	0	0	0	6	0	0	0	0	0	0	1	0	0	0	0	0	0	0
.063	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.065	11	0	0	0	3	0	0	0	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.067	2	0	0	0	4	0	0	0	31	0	0	0	0	0	2	0	19	0	7	0	3	0	1
.069	5	0	0	0	6	0	1	0	11	0	0	0	0	0	0	1	2	0	1	0	7	0	0
.071	9	0	3	0	2	0	0	0	16	0	0	0	0	0	0	0	0	0	1	0	0	0	1
.075	19	0	2	0	6	0	1	0	119	1	2	1	0	0	2	0	0	0	1	0	1	0	2
.077	13	0	1	0	3	0	0	0	23	0	0	0	0	0	2	1	1	0	0	0	4	0	0
.079	17	0	1	0	24	0	0	2	21	0	0	0	0	0	2	0	42	0	0	0	3	0	2
.081	29	0	0	0	15	0	0	0	59	0	0	0	0	0	2	0	30	0	0	0	2	0	1
.084	14	0	0	0	5	0	0	0	6	0	0	0	0	0	0	0	8	0	0	0	0	0	0
.087	13	0	1	0	6	0	0	0	10	0	0	0	0	0	0	0	1	0	0	0	0	0	0

PPENDIX TABLE 3.—Counts of selected categories of fish larvae, tabulated by station, EASTROPAC I.—*Continued.*

STATION NUMBER	Bathylagus nigrigenys	Leuroglossus stilbius urotranus	Nansenia spp.	Araiophos sp.	Cyclothone spp.	Diplophos sp.	Ichthyococcus spp.	Maurolicus muelleri	Vinciguerria spp.	Bathophilus filifer	Evermannellidae	Macroparalepis macrurus	Sudis atrox	Scopelo saurus spp.	Oxyporhamphus micropterus	Trachypteridae	Auxis spp.	Katsuwonis pelamis	Coryphaena spp.	Naucrates ductor	Howella pammelas	Tetragonurus sp.	Ceratioidei
12.090	4	0	2	0	2	0	1	7	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.092	0	0	0	0	5	0	0	4	41	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.094	3	0	0	0	8	0	0	1	124	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.097	3	0	0	0	7	0	0	8	46	0	0	0	0	0	0	1	0	0	0	0	0	0	1
12.100	12	0	3	0	4	0	0	0	10	0	0	0	0	0	0	1	1	0	0	0	1	0	0
.103	0	0	0	0	3	0	0	1	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.106	26	0	5	0	6	0	0	0	35	0	0	0	0	0	1	1	3	0	0	0	0	0	0
.109	1	0	2	0	7	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.112	6	0	1	0	1	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.115	17	0	4	0	0	0	0	0	12	0	0	0	0	0	0	0	36	0	3	0	0	0	1
.118	0	0	0	0	18	0	0	0	141	0	1	0	0	0	1	0	11	0	2	0	3	0	1
.120	0	0	0	0	2	0	0	0	4	0	0	0	0	0	0	0	3	0	0	0	0	0	0
.122	0	0	0	0	1	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.124	0	0	0	0	3	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.126	0	0	0	0	4	0	0	0	18	0	0	0	0	0	0	1	0	0	0	0	0	0	0
.128	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.132	0	0	0	0	1	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.134	0	0	0	0	10	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.136	0	0	0	0	3	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.138	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.140	0	0	0	0	3	0	0	0	18	0	0	0	0	0	0	0	0	2	0	0	0	0	2
.142	0	0	0	0	22	2	0	0	86	0	0	0	0	0	0	0	1	1	0	0	0	0	0
.144	0	0	0	0	15	0	0	0	147	0	0	1	0	0	0	0	0	0	0	0	0	0	1
.146	0	0	0	0	0	1	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.148	0	0	0	0	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.150	0	0	0	0	28	2	0	0	6	1	0	0	0	0	0	0	0	16	1	0	0	0	0
.152	0	0	0	0	9	1	0	0	5	0	2	0	0	0	0	0	0	0	0	0	0	0	0
.154	0	0	0	0	8	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.156	0	0	0	0	7	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0
.158	0	0	0	0	42	0	0	0	8	0	0	2	1	1	0	0	0	0	0	0	0	0	0
.160	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.162	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.164	0	0	0	0	24	1	0	0	15	0	0	0	0	0	0	1	0	0	0	0	0	0	0
.184	0	0	0	0	31	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.186	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0
.188	0	0	0	0	2	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.190	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
.192	0	0	0	0	14	1	1	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.194	0	0	0	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.196	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.198	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.200	0	0	0	0	3	0	0	0	3	0	1	0	0	0	1	0	13	0	0	0	0	0	0
.203	1	0	0	0	1	0	0	0	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0
.206	4	0	1	0	0	0	0	0	15	1	0	0	0	0	0	0	1	0	0	0	0	0	0
.209	4	0	5	0	3	0	2	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0
.212	16	0	0	0	17	0	0	0	17	0	0	0	0	0	0	0	5	0	1	0	0	0	0
.215	7	0	2	0	16	0	2	0	27	0	0	0	0	1	0	2	12	0	1	0	0	0	1
.218	1	0	4	0	9	0	0	2	11	0	0	0	0	0	0	0	6	0	0	0	0	0	4
.221	2	0	3	0	15	0	4	9	16	0	0	0	0	0	0	0	0	0	1	0	0	0	0
.224	0	0	0	0	48	0	0	2	201	0	0	0	0	0	0	0	2	0	0	0	0	0	2
.227	1	0	0	0	8	0	0	5	81	1	0	0	0	1	1	0	1	0	0	0	0	0	1
.230	3	0	6	0	1	0	0	0	4	0	0	0	0	0	0	1	0	0	0	0	0	0	0
.233	45	0	3	0	3	0	1	2	46	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX TABLE 3.—Counts of selected categories of fish larvae, tabulated by station, EASTROPAC I.—*Continued.*

STATION NUMBER	Bathylagus nigrigenys	Leuroglossus stilbius urotranus	Nansenia spp.	Araiophos sp.	Cyclothone spp.	Diplophos sp.	Ichthyococcus spp.	Maurolicus muelleri	Vinciguerria spp.	Bathophilus filifer	Evermannellidae	Macroparalepis macrurus	Sudis atrox	Scopelo saurus spp.	Oxyporhamphus micropterus	Trachypteridae	Auxis spp.	Katsuwonis pelamis	Coryphaena spp.	Naucrates ductor	Howella pammelas	Tetragonurus sp.	Ceratioidei
12.235	25	0	1	0	9	0	1	0	49	0	0	0	0	0	0	0	11	0	0	0	0	0	1
.238	17	0	0	0	7	0	1	0	31	3	0	1	0	0	0	0	17	0	0	0	0	0	0
.240	11	0	1	0	3	2	0	0	14	3	0	1	0	0	0	0	23	0	1	0	2	0	1
.242	1	0	2	0	1	0	0	0	0	7	0	0	0	0	2	0	12	0	1	0	3	0	0
.244	3	0	0	0	8	2	0	0	4	2	0	0	0	0	1	0	9	0	2	0	22	0	5
.246	11	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	8	0	1	0	7	0	2
.248	1	0	0	0	0	0	0	0	6	0	0	0	0	0	0	1	1	0	2	0	1	0	0
.250	1	0	0	0	1	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.252	1	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.254	1	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.256	3	0	0	0	0	1	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0
.258	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.260	2	0	0	0	4	1	0	0	15	0	0	0	0	0	0	0	0	0	0	0	2	0	2
.262	2	0	0	0	0	5	0	0	97	3	0	0	0	0	0	0	0	0	0	1	0	0	0
.264	2	0	0	0	0	6	0	0	14	1	0	0	0	0	0	0	0	0	0	1	0	0	0
.265	3	0	0	0	0	7	0	0	11	1	0	0	0	0	0	0	0	0	0	0	0	0	0
.268	0	0	0	0	0	2	0	0	103	1	0	0	0	0	0	0	0	0	2	0	0	0	2
.270	1	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.272	4	0	0	0	0	5	0	0	38	0	0	0	0	0	0	0	0	0	0	0	0	0	2
.274	0	0	0	0	0	4	0	0	36	1	0	0	0	0	0	0	0	0	0	0	0	0	0
.276	0	0	0	0	0	0	0	0	138	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.278	1	0	0	0	0	1	0	0	164	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.280	0	0	0	0	2	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.282	1	0	0	0	0	2	0	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.284	0	0	0	0	1	1	0	0	118	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.001	8	0	0	0	3	0	0	0	90	0	0	0	0	0	0	0	1	0	0	0	0	0	0
.003	14	0	0	0	35	0	0	0	1130	1	1	2	0	0	0	0	0	0	0	0	1	0	0
.005	54	0	0	0	6	1	2	0	300	0	0	0	0	0	0	0	3	0	1	0	0	0	0
.007	9	0	0	0	2	0	0	0	11	0	0	0	0	0	0	0	7	0	0	0	0	0	1
.009	8	0	0	0	1	0	0	0	9	0	0	0	0	0	0	0	7	0	0	0	0	0	0
.011	6	1	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
.013	18	0	0	0	0	0	1	0	8	0	0	0	0	0	1	0	1	0	0	0	0	0	0
.015	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0
.017	16	0	0	0	1	0	1	0	61	1	0	0	0	0	0	1	8	0	1	0	0	0	0
.019	9	0	0	0	0	0	0	0	82	0	0	0	0	0	9	0	33	0	1	0	0	0	1
.021	4	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	20	0	0	0	0	0	0
.022	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
.028	4	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	1	0	0	0	0	0	0
.030	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	2
.032	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0	52	0	0	0	0	0	8
.034	23	0	0	0	1	0	0	0	60	0	0	0	0	0	4	0	41	0	0	0	1	0	3
.036	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.038	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
.040	20	0	0	0	5	0	2	0	10	1	0	0	0	0	0	0	20	0	0	0	0	0	1
.042	11	0	0	0	5	0	3	0	6	0	0	0	0	0	0	1	4	0	0	0	0	0	0
.044	10	0	0	0	3	0	0	0	11	0	0	0	0	0	0	1	1	0	0	0	0	0	0
.046	10	0	0	0	5	0	0	0	73	4	0	0	0	0	0	1	0	0	1	0	0	0	0
.048	29	0	0	0	19	0	0	0	291	2	0	0	0	0	1	0	1	0	1	0	6	0	4
.050	10	0	0	0	5	0	0	0	36	1	0	0	0	0	0	0	0	0	0	0	0	0	0
.052	13	0	0	0	16	0	1	1	181	0	0	4	0	0	0	0	0	0	1	0	5	0	0
.054	14	0	1	0	9	1	0	5	76	4	0	0	0	0	3	0	11	0	0	0	0	0	1
.056	33	0	1	0	29	0	2	27	454	16	1	1	0	0	0	0	0	0	0	0	6	0	0
.058	6	0	0	0	8	0	1	10	319	1	0	0	0	0	0	0	7	0	0	0	0	0	0

PPENDIX TABLE 3.—Counts of selected categories of fish larvae, tabulated by station, EASTROPAC I.—*Continued.*

STATION NUMBER	Bathylagus nigrigenys	Leuroglossus stilbius urotranus	Nansenia spp.	Araiophos sp.	Cyclothone spp.	Diplophos sp.	Ichthyococcus spp.	Maurolicus muelleri	Vinciguerria spp.	Bathophilus filifer	Evermannellidae	Macroparalepis macrurus	Sudis atrox	Scopelo saurus spp.	Oxyporhamphus micropterus	Trachypteridae	Auxis spp.	Katsuwonis pelamis	Coryphaena spp.	Naucrates ductor	Howella pammelas	Tetragonurus sp.	Ceratioidei
13.060	5	0	0	0	2	0	2	14	8	0	0	0	0	0	0	0	17	0	0	0	0	0	0
.062	7	0	0	0	0	0	0	3	5	0	0	0	0	0	0	0	1	0	0	0	0	0	0
.064	15	0	0	0	5	0	3	18	45	0	0	0	0	0	0	0	1	0	0	0	0	0	0
.065	2	0	0	0	4	0	1	11	56	0	0	0	0	0	0	0	0	0	0	0	1	0	0
.067	7	0	0	0	2	0	0	0	52	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.069	37	0	1	0	2	0	0	13	45	1	0	0	0	0	0	0	1	0	0	0	0	0	0
.071	37	0	0	0	17	0	0	0	555	6	0	0	0	0	1	0	14	0	4	0	0	0	1
.073	42	0	0	0	13	0	0	0	153	1	0	0	0	0	0	0	3	0	4	0	0	0	5
.075	8	0	0	0	3	0	0	0	18	0	0	0	0	0	0	0	1	0	1	0	0	0	0
.077	0	0	0	0	0	0	0	0	59	2	0	0	0	0	0	0	5	0	0	0	0	0	2
.079	0	0	0	0	1	0	0	0	134	0	0	0	0	0	0	0	5	0	0	0	0	0	1
.081	2	0	0	0	0	0	0	0	164	0	0	1	0	0	0	0	0	0	0	0	0	0	1
.083	5	0	0	0	0	0	0	0	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.085	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.087	0	0	0	0	2	0	0	0	64	0	0	0	0	0	0	0	0	0	0	0	0	0	2
.089	0	0	0	0	9	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	2
.091	0	0	0	0	0	0	0	0	11	0	0	1	0	0	0	0	2	0	1	0	1	0	0
.093	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.095	6	0	0	0	25	1	0	0	120	2	1	1	0	0	0	0	10	0	0	0	0	0	1
.097	3	0	0	0	11	0	1	0	87	1	1	2	0	0	0	0	1	0	0	0	0	0	0
.099	0	0	0	0	4	1	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.101	3	0	0	0	0	0	1	0	7	0	0	2	0	0	0	0	0	6	1	0	0	0	0
.103	1	0	0	0	36	0	0	0	125	1	2	2	0	0	0	0	0	0	0	0	0	0	6
.105	0	0	0	0	20	0	0	0	30	0	0	1	0	0	0	0	0	0	0	0	0	1	2
.107	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.109	0	0	0	0	1	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.111	0	0	0	0	7	0	0	0	11	0	0	0	0	1	0	0	0	0	0	0	0	0	0
.113	0	0	0	0	12	0	0	0	18	0	0	1	1	0	0	1	0	0	0	0	0	0	1
.115	0	0	0	0	4	0	0	0	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0
.117	0	0	0	0	4	1	0	0	4	1	0	0	1	0	0	0	0	0	0	0	0	1	0
.119	0	0	0	0	26	3	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.121	0	0	0	0	10	0	1	0	6	0	0	0	1	0	0	0	0	0	0	0	0	0	0
.123	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.125	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.127	0	0	0	0	13	0	0	0	7	0	0	0	1	0	0	0	0	0	0	0	0	0	0
.129	0	0	0	0	9	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.131	0	0	0	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.133	0	0	0	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.135	0	0	0	0	46	0	0	0	10	0	0	0	1	0	0	0	0	0	0	0	0	0	0
.137	0	0	0	0	12	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.139	0	0	0	0	3	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.141	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.143	0	0	0	0	21	0	0	0	55	0	0	0	1	0	0	0	5	0	0	0	0	0	0
.145	0	0	0	0	12	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.147	0	0	0	0	1	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	3
.149	0	0	0	0	6	0	0	0	8	0	0	0	0	0	0	1	0	0	1	0	0	0	0
.151	0	0	0	0	7	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.153	0	0	0	0	44	0	0	0	59	0	3	0	0	0	0	0	0	0	0	0	0	0	0
.155	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	2
.157	0	0	0	0	3	0	0	0	5	0	0	0	0	0	0	0	1	0	0	0	0	0	0
.159	0	0	0	0	8	1	0	0	3	0	1	1	0	0	0	0	4	0	0	0	0	0	0
.161	0	0	0	0	11	0	0	0	13	0	0	1	0	0	0	0	0	0	0	0	0	0	0
.163	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.165	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX TABLE 3.—Counts of selected categories of fish larvae, tabulated by station, EASTROPAC I.—*Continued.*

STATION NUMBER	Bathylagus nigrigenys	Leuroglossus stilbius urotranus	Nansenia spp.	Araiophos sp.	Cyclothone spp.	Diplophos sp.	Ichthyococcus spp.	Maurolicus muelleri	Vinciguerria spp.	Bathophilus filifer	Evermannellidae	Macroparalepis macrurus	Sudis atrox	Scopelo saurus spp.	Oxyporhamphus micropterus	Trachypteridae	Auxis spp.	Katsuwonis pelamis	Coryphaena spp.	Naucrates ductor	Howella pammelas	Tetragonurus sp.	Ceratioidei
13.167	0	0	0	0	5	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.169	0	0	0	0	7	0	0	0	76	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.171	0	0	0	0	2	0	0	0	16	0	0	0	0	0	0	0	13	0	0	0	0	0	0
.173	7	0	0	0	0	0	0	0	4	0	0	1	0	0	0	0	6	0	0	0	0	0	0
.175	22	0	0	0	6	0	0	0	169	0	1	1	0	0	0	0	45	0	0	0	1	0	1
.179	15	0	0	0	6	0	0	0	105	0	0	0	0	0	1	0	7	0	0	0	0	0	1
.183	50	0	3	0	3	0	0	0	36	0	0	0	0	0	0	0	6	0	0	0	0	0	0
.187	43	0	2	0	3	0	0	0	26	0	0	0	0	0	0	0	0	0	1	0	0	0	0
.191	10	0	6	0	25	0	0	5	118	0	0	0	0	0	1	0	7	0	0	0	0	0	1
.195	10	0	0	0	8	0	0	0	194	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.199	5	0	0	0	1	0	0	2	25	0	0	0	0	0	0	0	0	0	0	0	0	0	1
13.203	3	0	1	0	2	0	0	9	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.207	11	0	0	0	11	0	0	7	143	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.211	5	0	0	0	6	0	2	1	27	0	0	0	0	0	0	0	1	0	0	0	0	0	0
.215	6	0	0	0	3	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.219	9	0	0	0	1	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.223	2	0	0	0	3	0	0	2	15	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.227	9	0	0	0	14	0	0	4	20	0	0	0	0	0	3	0	1	0	0	0	0	0	0
.231	9	0	1	0	5	0	0	0	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.235	9	0	1	0	3	0	2	0	31	0	0	0	0	0	1	0	1	0	0	0	0	0	0
.237	6	0	0	0	12	0	2	0	33	0	0	1	0	0	0	0	7	0	1	1	0	0	0
.239	3	0	0	0	7	0	3	0	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.241	2	0	0	0	1	0	0	0	4	0	0	0	0	0	0	0	1	0	0	0	0	0	0
.243	11	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.245	7	0	0	0	1	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.247	9	0	0	0	0	0	0	0	11	0	0	0	0	0	0	1	2	0	1	0	0	0	0
.249	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.251	6	0	0	0	0	0	0	0	10	2	0	0	0	0	0	0	3	0	0	0	0	0	0
.253	20	0	0	0	0	0	0	0	22	4	0	0	0	0	0	0	0	0	0	0	0	0	0
.255	7	0	0	0	0	0	0	0	29	0	0	0	0	0	1	0	15	0	1	0	0	0	3
.257	8	0	0	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0
.259	17	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	5	0	0	0	0	0	0
.261	8	0	0	0	1	0	0	0	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.263	19	0	0	0	0	0	0	0	54	0	0	0	0	0	1	0	11	0	0	0	0	0	0
.265	6	0	0	0	0	1	0	0	12	8	0	0	0	0	0	0	1	0	0	0	0	0	1
.266	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0
.268	3	0	0	0	0	0	0	0	26	0	0	0	0	0	0	0	1	0	0	0	0	0	0
.270	4	0	0	0	0	2	0	0	18	3	0	0	0	0	12	0	1	0	0	0	0	0	1
.272	2	0	0	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0
.274	1	0	0	0	0	3	0	0	49	6	0	0	0	0	3	0	1	0	1	0	0	0	0
.276	5	0	0	0	0	2	0	0	89	3	0	0	0	0	3	0	19	0	0	0	0	0	0
.278	1	0	0	0	0	1	0	0	20	2	0	0	0	0	0	0	0	0	0	0	0	0	0
.280	8	0	0	0	0	3	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
.282	0	0	0	0	0	3	0	0	33	6	0	0	0	0	1	0	0	0	1	0	0	0	0
.284	18	0	0	0	1	0	0	0	60	1	0	0	0	0	2	0	0	0	0	0	0	0	1
13.318	13	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1
.320	8	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	13	0	0	0	0	0	0
.322	0	0	0	0	0	0	0	0	5	0	0	0	0	0	1	0	9	0	1	0	0	0	0
.324	10	0	0	0	0	0	0	0	4	0	0	0	0	0	2	0	4	0	0	0	0	0	0
.326	13	0	0	0	1	0	0	0	9	0	0	0	0	0	0	0	18	0	0	0	0	0	1
.328	2	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	7	0	0	0	0	0	0
.330	4	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.332	11	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	1

APPENDIX TABLE 3.—Counts of selected categories of fish larvae, tabulated by station, EASTROPAC I.—*Continued.*

STATION NUMBER	Bathylagus nigrigenys	Leuroglossus stilbius urotranus	Nansenia spp.	Araiophos sp.	Cyclothone spp.	Diplophos sp.	Ichthyococcus spp.	Maurolicus muelleri	Vinciguerria spp.	Bathophilus filifer	Evermannellidae	Macroparalepis macrurus	Sudis atrox	Scopelo saurus spp.	Oxyporhamphus micropterus	Trachypteridae	Auxis spp.	Katsuwonis pelamis	Coryphaena spp.	Naucrates ductor	Howella pammelas	Tetragonurus sp.	Ceratioidei
13.334	37	0	0	0	2	0	0	0	19	1	0	0	0	0	0	1	0	0	0	0	0	0	2
.338	9	0	1	0	1	0	0	0	48	0	0	0	0	0	2	0	5	0	0	0	0	0	0
.340	4	0	0	0	3	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	1	0	0
.342	9	0	1	0	8	0	0	2	14	0	0	0	0	0	0	0	4	0	0	0	0	0	0
14.001	9	30	0	0	3	0	0	0	94	0	0	0	0	0	0	0	8	0	0	0	0	0	0
.006	3	29	0	0	3	0	0	0	15	0	0	0	0	0	0	0	10	0	0	0	0	0	0
.008	9	25	1	0	0	0	0	0	4	0	0	0	0	0	0	0	1	0	1	0	0	0	1
.010	1	13	0	0	3	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.012	2	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.014	3	39	0	0	0	0	0	0	4	0	0	0	0	0	0	0	2	0	0	0	0	0	0
.016	10	9	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
.017	11	6	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.018	24	17	0	0	6	0	0	0	42	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.020	6	0	0	0	0	0	0	0	10	0	0	0	0	0	0	1	0	0	0	0	0	0	0
.022	1	6	0	0	3	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.024	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.027	17	6	0	0	1	0	0	0	30	0	0	0	0	0	0	0	6	0	0	0	0	0	0
.029	13	11	0	0	1	0	0	0	41	0	0	0	0	0	0	0	0	0	2	0	0	0	2
.031	29	1	0	0	2	0	0	0	41	0	0	0	0	1	0	0	1	0	1	0	0	0	0
.033	20	1	0	0	0	0	1	0	4	0	0	0	0	0	0	0	0	0	0	1	0	0	0
.040	48	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	6	0	2	0	0	0	0
.043	59	6	0	0	3	0	0	0	14	1	0	0	0	6	0	0	22	0	0	0	0	0	5
.047	49	62	0	0	0	0	0	1	2	0	0	0	0	0	2	0	9	0	1	1	0	0	0
.051	20	205	0	0	2	0	0	0	25	0	0	0	0	0	0	0	46	0	0	1	0	0	0
.055	2	152	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.060	0	139	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.066	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.069	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.076	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.078	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.081	2	0	0	0	3	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.084	0	2	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.086	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.088	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.091	2	0	0	0	8	0	0	0	32	1	0	0	0	0	0	0	0	0	1	0	0	0	2
.095	2	0	0	0	2	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
.099	2	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.106	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.110	0	0	0	0	5	0	0	0	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0
.112	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.114	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.115	2	0	0	0	1	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	2
.117	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.120	1	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	1	0	0	0	0	0	0
.122	2	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.123	7	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	2
.124	7	0	0	0	18	0	0	0	58	0	0	0	0	0	0	1	0	0	1	0	0	0	8
.126	3	0	0	0	3	0	1	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.127	5	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.128	5	0	0	0	4	0	0	0	56	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.130	3	0	0	0	2	0	0	0	42	0	0	0	0	0	0	0	4	0	0	0	0	0	0

APPENDIX TABLE 3.—Counts of selected categories of fish larvae, tabulated by station, EASTROPAC I.—*Continued.*

STATION NUMBER	Bathylagus nigrigenys	Leuroglossus stilbius urotranus	Nansenia spp.	Araiophos sp.	Cyclothone spp.	Diplophos sp.	Ichthyococcus spp.	Maurolicus muelleri	Vinciguerria spp.	Bathophilus filifer	Evermannellidae	Macroparalepis macrurus	Sudis atrox	Scopelo saurus spp.	Oxyporhamphus micropterus	Trachypteridae	Auxis spp.	Katsuwonis pelamis	Coryphaena spp.	Naucrates ductor	Howella pammelas	Tetragonurus sp.	Ceratioidei
14.131	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.132	8	0	0	0	0	0	0	0	17	0	0	0	0	0	0	1	0	0	1	0	0	0	2
.134	0	0	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1
.136	1	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.138	9	0	0	0	2	0	0	0	90	0	0	0	0	0	0	0	9	0	0	0	0	0	0
.142	1	0	0	0	0	0	0	0	53	4	0	0	0	0	0	0	1	0	0	0	0	0	1
.146	16	30	0	0	0	0	0	0	111	1	0	0	0	0	0	0	8	0	0	0	0	0	0
.150	33	1	0	0	2	0	0	1	45	0	0	0	0	0	4	1	5	0	0	0	0	0	0
.154	28	6	0	0	9	0	1	0	372	0	0	0	0	0	1	0	7	0	0	0	0	0	3
.158	0	0	0	0	4	0	0	1	219	1	0	0	0	0	0	0	0	0	0	0	0	0	1
.164	8	0	0	0	4	0	1	0	48	0	0	0	0	3	0	0	6	0	0	0	0	0	1
.172	1	0	0	0	2	0	0	5	90	0	0	0	0	0	0	0	12	0	0	0	0	0	0
.174	3	0	0	0	0	0	1	3	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.177	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.183	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.188	34	0	0	0	4	0	0	9	155	1	0	0	0	0	2	0	36	0	1	0	0	0	1
.194	161	0	0	0	7	0	0	22	98	0	0	0	0	0	0	1	22	0	1	0	0	0	4
.195	54	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	2	0	0	0	0
.199	15	0	0	0	5	0	0	0	196	0	0	0	0	0	0	1	20	0	0	0	0	0	3
14.203	3	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	1
.209	5	0	0	0	0	0	0	0	2	0	0	0	0	0	10	0	0	0	0	0	0	0	0
.213	34	0	0	0	10	0	0	0	86	0	0	0	0	0	0	0	11	0	1	0	0	0	0
.218	27	0	0	0	1	0	0	0	38	0	0	0	0	0	2	1	4	0	2	0	0	0	0
.220	2	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	13	0	0	0	0	0	0
.222	2	0	0	0	0	0	0	0	4	2	0	0	0	0	0	0	1	0	0	0	0	0	0
.224	9	3	0	0	6	0	0	0	31	1	0	0	0	0	0	0	7	0	0	0	1	0	0
.228	2	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	2	0	0	0	0	0	0
.230	1	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	9	0	0	0	0	0	0
.232	9	0	0	0	0	0	0	0	49	0	0	0	0	0	0	0	12	0	0	0	0	0	0
.234	9	0	0	0	2	0	0	0	867	0	0	0	0	0	0	1	161	1	0	0	0	0	0
.236	3	0	0	0	0	0	0	0	16	0	0	0	0	0	0	1	10	0	0	0	0	0	0
.240	21	0	0	0	0	1	0	4	31	0	0	0	0	0	0	0	85	0	0	0	0	0	1
.243	24	0	0	0	1	0	0	7	19	0	0	0	0	0	0	0	5	0	0	0	0	0	0
.247	4	0	0	0	0	0	0	13	39	0	0	0	0	0	0	0	1	0	0	0	0	0	0
.251	8	3	0	0	1	0	0	1	23	0	0	0	0	0	0	0	1	0	0	0	0	0	6
.255	1	209	0	0	10	0	0	0	76	0	0	0	0	0	0	0	59	0	1	0	0	0	6
.259	16	0	0	0	0	0	0	0	40	1	0	0	0	0	0	0	0	0	0	0	0	0	5
.263	2	0	0	0	2	0	0	0	231	0	0	0	0	0	0	0	0	0	0	0	0	0	2
.267	3	0	0	0	0	0	0	0	33	0	0	0	0	0	0	1	0	0	2	0	0	0	3
.276	9	0	0	0	6	0	0	0	52	0	0	0	0	0	0	0	0	0	2	0	0	0	1
.280	7	0	0	0	3	0	0	0	59	2	0	0	0	0	0	0	0	0	2	0	0	0	6
.283	3	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	1	0	0	0	1
.287	5	0	0	0	3	0	0	0	59	0	0	0	0	0	0	0	0	0	0	0	0	0	9
.291	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.295	4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	63	0	2	0	0	0	5
.300	1	286	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
.303	3	490	0	0	2	0	0	0	8	0	0	0	0	0	0	0	0	0	1	0	1	0	1
.306	12	22	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.310	70	21	0	0	0	0	0	9	12	1	0	0	0	0	0	0	0	0	0	0	0	0	0
.314	24	0	0	0	1	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.318	32	0	0	0	2	0	0	2	66	0	0	0	0	0	0	0	1	0	0	0	0	0	1
.323	11	0	0	0	0	0	0	0	24	1	0	0	0	0	0	0	0	0	0	0	0	0	0
.326	15	12	0	0	1	0	0	0	65	0	0	0	0	0	0	0	8	0	0	0	0	0	0
.330	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PPENDIX TABLE 4.—Summary of occurrences and numbers of larvae of eight families, limited in distribution to a broad coastal band or around offshore islands.

STATION NUMBER	Clupeidae	Engraulidae	Synodontidae	Carangidae	Serranidae	Labridae	Gobiidae	Scorpaenidae
11.076	0	0	0	1	0	0	0	0
11.246	0	0	0	0	0	0	0	1
12.020	0	0	0	0	0	1	0	0
.024	0	0	0	1	4	0	0	0
.026	0	0	0	0	10	0	0	0
.028	0	0	0	0	0	0	3	3
.030	0	0	0	0	0	0	1	1
.031	0	0	0	0	0	0	7	0
.033	1	2	1	2	1	2	1	1
.035	0	0	0	5	0	0	3	1
.041	0	0	0	1	0	0	1	0
.059	0	0	0	0	0	0	1	0
12.221	0	0	0	0	0	0	0	2
.256	0	0	0	0	0	1	0	0
.262	0	0	0	1	0	0	0	0
.264	0	0	0	1	0	0	0	0
.268	0	0	0	1	0	0	0	0
13.003	0	0	0	1	0	0	1	0
.005	0	0	0	0	0	0	1	1
.007	0	0	0	0	0	0	0	1
.011	0	0	0	0	0	0	1	0
.019	0	13	1	70	49	2	47	12
.021	2	7	0	11	3	0	3	1
.030	0	0	0	0	0	0	1	2
.032	0	0	0	0	0	0	12	8
.034	0	0	0	0	0	0	23	3
.040	0	0	0	0	0	0	0	1
.042	0	0	0	0	0	1	0	0
.054	0	0	0	0	1	0	0	0
.056	0	0	0	0	0	0	1	0
.062	0	0	0	0	0	2	0	0
13.235	0	0	0	0	0	0	0	1
.237	0	0	0	1	0	0	0	0
.239	0	0	0	0	0	0	2	0
.245	0	0	0	0	0	0	13	0
.247	0	0	0	0	0	0	5	0
.249	0	0	0	0	0	0	1	0
.253	0	0	0	0	0	0	72	0
.255	2	0	1	2	0	0	2	3
.257	0	0	0	0	0	0	0	1
.261	0	0	0	0	0	0	41	0
.263	0	0	0	0	0	0	0	2
.265	0	0	0	0	0	0	0	1
.266	0	0	0	0	0	1	0	0
.268	0	0	0	0	0	1	0	0
.274	0	0	0	0	0	0	3	0
.276	0	0	0	0	0	0	2	0
13.320	1	0	0	0	0	1	7	3
.328	0	0	0	0	0	0	2	1
.330	0	0	0	0	0	0	4	0
.334	0	0	0	0	0	0	1	0
.338	0	0	0	0	0	0	17	0
14.001	0	5	1	1	84	0	55	11
.006	0	0	0	0	1	0	5	1
.008	0	0	0	0	0	0	2	5
.010	0	0	0	0	0	0	3	2
.012	0	0	1	0	0	1	1	0
.014	6	0	0	4	0	0	11	1
.016	0	0	0	34	0	0	0	0
.017	0	0	0	0	0	1	0	0
.018	0	0	0	0	0	3	10	4
.020	0	0	0	0	0	1	1	1
.022	0	0	0	0	14	0	2	1
.024	0	4	0	6	5	0	0	6
.027	0	0	3	5	1	4	36	9
.029	0	0	7	2	12	0	9	37
.031	0	0	3	0	3	1	18	4
.033	0	0	0	1	0	1	1	2
.040	0	0	0	6	5	0	1	0
.043	0	0	0	0	0	1	2	0
.047	0	0	0	1	0	1	0	3
.051	0	0	0	1	0	0	0	0
.055	0	0	0	0	0	1	0	0
.060	0	52	0	2	0	0	0	0
.066	0	11	0	0	0	0	0	0
.069	0	97	0	0	0	0	0	0
.076	0	11	0	0	0	0	0	0
14.106	0	3	0	0	0	0	0	0
.110	0	0	0	1	0	0	0	0
.154	0	0	0	0	5	0	0	1
.158	5	0	0	1	8	0	3	4
.164	0	0	0	0	0	0	0	1
.172	2	0	0	11	22	3	0	1
.174	1	0	0	0	4	2	1	1
.177	60	0	0	2	6	1	1	0
.194	1	0	0	1	0	1	0	0
.195	0	0	0	0	2	0	0	0
.199	0	0	0	2	0	0	1	0
14.209	0	0	0	0	0	1	0	0
.213	0	0	0	0	0	0	3	0
.220	0	0	0	0	0	1	1	0
.222	0	0	0	0	0	1	0	0
.224	0	0	0	3	0	0	0	1
.228	0	0	0	0	1	0	0	4
.230	0	0	0	2	0	0	0	2
.232	0	0	0	0	0	0	2	0
.234	0	0	0	0	3	0	8	3
.236	0	0	0	0	0	0	1	0
.240	0	0	0	0	0	0	1	1
.243	0	0	0	0	0	0	1	0
.247	0	0	0	0	0	0	2	0
14.303	0	0	0	0	1	1	0	0
.314	0	0	0	0	0	0	0	1
.318	0	0	10	0	4	2	43	5
.323	0	0	0	0	1	0	3	1
.326	0	0	13	0	2	0	23	0

APPENDIX TABLE 5.—Numbers and kinds of larvae of Gempylidae-Trichiuridae obtained in EASTROPAC I collections.

STATION NUMBER	Nealotus tripes	Gempylus serpens	Diplospinus multistriatus	Lepidopus sp.	Other	STATION NUMBER	Nealotus tripes	Gempylus serpens	Diplospinus multistriatus	Lepidopus sp.	Other
11.056	0	1	0	0	0	13.107	0	0	1	0	0
.064	0	0	1	0	0	.119	1	3	0	0	0
.072	0	1	0	0	0	.137	0	2	0	0	0
11.114	1	0	0	0	0	.139	0	0	1	0	0
.138	1	0	0	0	0	.147	0	0	1	0	0
.140	1	0	0	0	0	.153	0	0	1	0	0
.146	0	1	0	0	0	.159	0	2	0	0	0
.158	1	0	0	0	0	.167	1	0	0	0	0
.159	1	0	0	0	0	.171	0	1	0	0	0
11.213	0	1	0	0	0	.173	1	0	0	0	0
.219	0	1	0	0	0	.175	1	0	0	0	0
.228	1	0	0	0	0	.179	0	3	0	0	0
.234	0	1	0	0	0	.187	0	0	0	0	2
.295	0	2	0	0	0	.191	0	1	0	0	0
.297	0	2	0	0	0	13.235	1	0	0	0	0
11.318	0	0	5	0	0	.245	0	1	0	0	0
.320	0	0	1	0	0	.280	0	0	0	0	1
.324	0	0	1	0	0						
.326	0	0	2	0	0	14.001	0	1	0	0	0
						.010	1	0	0	0	0
12.004	0	1	0	0	0	.012	0	0	0	1	0
.014	0	1	0	0	0	.029	1	0	1	1	0
.020	0	1	0	0	0	.031	1	0	0	0	0
.047	0	2	0	0	0	.095	0	0	1	0	0
.081	0	1	0	0	0	14.122	0	0	1	0	0
12.115	0	0	0	0	1	.123	0	0	1	0	0
.118	6	0	0	0	1	.124	1	1	1	0	0
.120	1	0	0	0	0	.126	1	0	1	0	0
.144	0	1	0	0	0	.127	0	0	3	0	0
.150	0	3	0	0	0	.128	0	0	6	0	0
.152	0	1	0	0	0	.130	0	0	3	0	0
.158	0	1	0	0	0	.131	0	0	1	0	0
.188	0	1	0	0	0	.134	1	1	0	0	0
12.246	0	2	0	0	0	.138	3	0	0	0	0
.260	0	1	0	0	0	.142	2	0	0	0	0
.262	0	1	0	0	0	.146	2	0	0	0	0
.272	0	1	0	0	0	.150	1	0	0	0	0
.276	0	1	0	0	0	.164	1	0	0	0	0
						.188	1	0	0	0	0
13.048	1	2	0	0	0	.194	0	0	0	2	0
.054	0	0	0	17	0	.195	1	0	0	0	0
.056	2	0	0	0	0	14.222	1	0	0	0	0
.071	6	0	0	0	0	.224	1	0	0	0	0
.073	7	0	0	0	0	.234	8	0	0	1	0
.075	2	0	0	0	0	.240	1	0	0	0	0
.077	3	0	0	0	0	.259	3	0	0	0	0
.081	8	0	0	0	0	.280	1	4	1	0	0
.083	0	1	0	0	0	.283	0	0	1	0	0
.095	0	0	7	0	0	.287	1	2	0	0	0
.097	0	1	4	0	0	.295	0	1	0	0	0
.101	0	1	6	0	0	14.318	1	0	0	2	0
.103	0	0	7	0	0	.326	0	0	0	1	0
.105	0	0	2	0	0	.330	1	0	0	0	0

PPENDIX TABLE 6.—Numbers and kinds of flatfish (Pleuronectiformes) larvae obtained in EASTROPAC I collections.

Station number	Bothus leopardinus	Citharichthus - Etropus	Cyclopsetta sp.	Engyophrys sancti-laurentii	Syacium ovale	Symphurus spp.	Other Pleuronectiformes
12.028	0	0	0	0	0	1	0
.030	0	1	0	0	0	0	0
.031	0	0	0	0	2	6	0
.033	4	1	0	0	6	6	0
.035	0	0	0	0	0	3	0
.045	0	0	0	0	0	1	0
13.007	0	0	0	0	1	0	0
.009	0	1	0	0	0	0	0
.011	0	1	0	0	0	0	0
.013	0	0	0	0	0	5	0
.015	1	0	0	0	0	1	0
.019	6	1	1	0	25	31	1
.021	2	2	0	0	13	8	0
.030	0	0	0	0	0	4	0
.032	0	0	0	0	0	8	0
.034	0	0	0	2	4	9	0
.036	0	0	0	0	1	0	0
.040	1	2	0	1	0	3	0
.042	1	0	1	0	6	1	0
.054	1	0	0	0	0	0	0
13.245	1	0	0	0	0	0	0
.251	0	0	0	0	0	1	0
.253	4	0	0	0	0	4	0
.255	3	1	0	0	0	9	0
.257	0	0	0	0	0	1	0
.259	0	0	0	0	1	1	0
.261	1	0	0	0	1	1	0
.263	1	0	0	0	3	8	0
.265	0	0	0	0	2	1	0
13.318	2	0	0	0	1	1	0
.320	2	0	0	0	0	2	0
.322	5	0	0	0	0	0	0
.324	0	0	0	0	1	0	0
.326	0	0	0	0	1	2	0
.328	0	0	0	0	0	1	0
.334	1	0	0	0	0	0	0

Station number	Bothus leopardinus	Citharichthys - Etropus	Cyclopsetta sp.	Engyophrys sancti-laurentii	Syacium ovale	Symphurus spp.	Other Pleuronectiformes
14.001	1	5	0	1	0	35	0
.006	0	1	0	0	0	2	0
.008	0	1	0	0	0	3	0
.010	0	1	0	1	0	1	0
.014	0	2	0	0	0	4	0
.016	0	0	0	0	0	5	1
.017	0	0	0	0	0	2	0
.018	0	1	0	0	0	1	0
.020	0	0	0	0	0	5	0
.022	1	3	0	0	0	1	0
.024	0	1	0	0	0	9	0
.027	1	6	0	1	3	9	0
.029	1	5	0	0	2	24	0
.031	0	0	0	1	0	30	0
.033	0	0	0	1	0	2	0
.040	0	1	0	0	2	4	0
.047	0	0	0	0	0	1	0
.055	0	1	0	0	0	2	0
14.164	1	0	0	0	0	1	0
.174	0	0	0	0	0	1	0
.183	0	0	0	0	0	1	0
.194	0	0	0	0	0	1	0
.195	0	0	0	0	0	1	0
.199	0	0	0	0	0	1	0
14.209	0	0	0	0	0	1	0
.213	0	0	0	0	1	0	0
.220	0	0	0	0	0	3	0
.228	0	1	0	0	0	3	0
.230	0	0	0	0	0	1	0
.232	0	0	0	0	1	0	0
.234	2	0	2	0	3	1	0
.236	1	0	0	0	0	2	0
.240	0	0	0	0	1	0	0
.259	2	0	0	0	0	0	0
.295	0	1	0	0	0	0	0
14.300	0	0	0	0	1	0	0
.303	1	1	0	0	0	1	0
.306	0	0	0	0	0	1	0
.314	0	0	0	0	0	1	0
.318	1	2	0	1	0	19	0
.323	1	3	0	0	2	2	0
.326	1	4	0	0	0	3	0
.330	0	0	0	0	0	1	0

APPENDIX TABLE 7.—Standardized haul factors (SHF): These factors are used to adjust original counts of larvae to the comparable standard of numbers of larvae in 10 m^3 of water strained per meter of depth fished.

Station	SHF	Station	SHF	Station	SHF	Station	SHF	Station	SHF
11.022	3.06	11.156	2.74	11.291	3.46	12.061	3.33	12.192	3.27
11.025	2.87	11.158	3.12	11.293	2.93	12.063	3.27	12.194	3.45
11.027	2.38	11.159	2.64	11.295	3.16	12.065	3.23	12.196	3.32
11.030	2.47	11.161	3.35	11.297	2.86	12.067	3.36	12.198	3.40
11.032	3.01	11.163	2.64	11.299	3.57	12.068	3.39	12.200	3.18
11.034	3.64	11.167	2.97	11.301	3.31	12.071	3.34	12.203	3.29
11.036	3.04	11.169	3.27	11.303	3.19	12.075	3.33	12.206	3.53
11.038	2.80	11.171	2.92	11.306	3.22	12.077	3.42	12.209	3.51
11.040	3.32	11.173	2.94	11.308	3.15	12.079	3.56	12.212	3.32
11.044	2.81	11.175	3.47	11.310	3.19	12.091	3.53	12.215	3.27
11.046	3.24	11.177	1.36	11.312	3.42	12.084	3.73	12.218	3.02
11.048	3.08	11.179	3.37	11.314	3.18	12.087	3.86	12.221	3.07
11.050	2.36	11.181	2.74	11.316	2.84	12.090	3.10	12.224	2.58
11.052	2.86	11.183	2.92	11.318	3.27	12.092	2.55	12.227	2.96
11.054	2.54	11.185	3.19	11.320	3.34	12.094	2.29	12.230	3.72
11.056	2.90	11.187	2.75	11.322	3.01	12.097	3.01	12.233	2.66
11.058	3.28	11.189	3.00	11.324	3.02	12.100	2.48	12.235	3.56
11.060	3.15	11.191	3.79	11.326	2.84	12.103	3.28	12.238	3.21
11.062	3.72	11.195	3.11	11.328	2.62	12.106	3.55	12.240	3.22
11.064	3.01	11.197	3.14			12.109	3.39	12.242	3.41
11.066	2.12	11.199	2.46	12.002	3.12	12.112	3.43	12.244	3.36
11.068	2.62	11.201	3.27	12.004	3.02	12.115	3.48	12.246	3.14
11.070	2.25	11.203	3.09	12.006	3.31	12.118	2.45	12.248	3.07
11.072	3.43	11.205	3.20	12.008	3.08	12.120	3.46	12.250	2.49
11.076	2.92	11.207	3.65	12.010	3.13	12.122	3.43	12.252	2.33
11.080	2.45	11.209	3.06	12.012	3.17	12.124	3.17	12.254	3.30
11.084	2.70	11.211	3.39	12.014	3.28	12.126	3.47	12.256	3.26
11.088	3.19	11.213	2.87	12.016	3.17	12.128	3.30	12.258	3.26
11.094	3.61	11.215	3.13	12.018	3.13	12.130	3.35	12.260	3.51
11.098	1.78	11.217	2.90	12.020	3.12	12.132	3.38	12.262	2.98
11.102	2.72	11.219	3.36	12.022	3.43	12.134	3.29	12.264	3.38
11.106	1.36	11.221	2.92	12.024	3.11	12.136	3.22	12.265	3.27
11.110	2.95	11.223	3.71	12.026	3.30	12.138	3.38	12.268	3.35
11.114	3.35	11.226	3.05	12.028	3.44	12.140	3.00	12.270	3.36
11.118	4.65	11.228	3.29	12.030	3.44	12.142	3.42	12.272	3.12
11.120	3.68	11.234	3.65	12.032	3.32	12.144	3.20	12.274	3.28
11.124	3.67	11.238	3.41	12.033	3.21	12.146	4.36	12.276	3.34
11.128	2.85	11.242	3.77	12.035	3.35	12.148	3.21	12.278	3.00
11.130	3.80	11.246	3.01	12.037	3.20	12.150	3.14	12.280	3.39
11.132	3.37	11.250	2.77	12.039	3.47	12.152	3.17	12.282	3.58
11.134	3.22	11.254	2.51	12.041	3.42	12.154	3.27	12.284	3.41
11.136	3.24	11.258	2.86	12.043	3.33	12.156	3.28		
11.138	3.38	11.262	3.23	12.045	3.35	12.158	3.22	13.001	2.26
11.140	2.77	11.266	2.91	12.047	3.42	12.160	3.49	13.003	2.45
11.142	3.35	11.270	3.69	12.049	3.39	12.162	3.21	13.005	1.42
11.146	3.25	11.278	3.09	12.051	3.31	12.164	2.98	13.007	2.42
11.148	2.54	11.282	3.99	12.053	3.27	12.184	3.22	13.009	2.56
11.150	3.45	11.285	3.20	12.055	2.84	12.186	3.22	13.011	3.68
11.152	2.59	11.287	3.45	12.057	3.22	12.188	3.35	13.013	2.29
11.154	3.40	11.289	3.12	12.059	3.41	12.190	3.39	13.015	2.76

PENDIX TABLE 7.—Standardized haul factors (SHF): These factors are used to adjust original counts of larvae the comparable standard of numbers of larve in 10 m^3 of water strained per meter of depth fished.—*Continued.*

Station	SHF	Station	SHF	Station	SHF	Station	SHF	Station	SHF
13.017	2.16	13.119	2.67	13.249	3.46	14.047	4.10	14.203	3.15
13.019	1.88	13.121	3.14	13.251	3.46	14.051	2.93	14.209	3.23
13.021	2.12	13.123	3.06	13.253	3.13	14.055	3.77	14.213	3.26
13.022	2.72	13.125	3.50	13.255	3.58	14.060	3.58	14.218	2.87
13.028	1.53	13.127	3.30	13.257	3.68	14.066	3.81	14.220	3.42
13.030	2.50	13.129	4.01	13.259	3.42	14.069	3.65	14.222	3.64
13.032	3.05	13.131	3.64	13.261	1.85	14.076	3.61	14.224	3.77
13.034	3.21	13.133	3.84	13.263	3.49	14.078	3.64	14.228	3.87
13.036	2.34	13.135	2.51	13.265	3.29	14.081	3.39	14.230	2.96
13.038	2.25	13.137	2.58	13.266	3.31	14.084	3.86	14.232	2.70
13.040	2.85	13.139	3.57	13.268	3.47	14.086	3.95	14.234	0.72
13.042	2.74	13.141	3.36	13.270	3.30	14.088	3.54	14.236	2.96
13.044	2.58	13.143	3.23	13.272	3.06	14.091	3.08	14.240	3.43
13.046	3.08	13.145	3.49	13.274	3.73	14.095	3.87	14.243	3.55
13.048	2.71	13.147	3.58	13.276	3.54	14.099	3.70	14.247	3.52
13.050	3.02	13.149	3.56	13.278	3.16	14.103	3.57	14.251	3.49
13.052	2.91	13.151	3.11	13.280	3.48	14.106	3.68	14.255	3.64
13.054	3.07	13.153	3.25	13.282	3.37	14.110	3.55	14.259	3.54
13.056	2.87	13.155	3.34	13.284	3.36	14.112	3.66	14.263	3.68
13.058	2.75	13.157	3.40	13.318	3.17	14.114	4.84	14.267	3.04
13.060	3.62	13.159	3.00	13.320	2.93	14.115	3.24	14.276	3.47
13.062	3.15	13.161	3.30	13.322	3.22	14.117	4.29	14.280	3.56
13.064	2.76	13.163	2.70	13.324	3.12	14.118	4.03	14.283	3.60
13.065	2.81	13.165	3.22	13.326	3.05	14.120	3.76	14.287	3.53
13.067	2.67	13.167	3.64	13.328	3.15	14.122	3.78	14.291	3.11
13.069	2.12	13.169	3.25	13.330	3.03	14.123	3.51	14.295	2.28
13.071	2.61	13.171	3.12	13.332	3.13	14.124	3.38	14.300	3.58
13.073	3.11	13.173	2.80	13.334	2.85	14.126	3.69	14.303	3.48
13.075	3.42	13.175	2.71	13.338	3.02	14.127	3.89	14.306	3.29
13.077	2.72	13.179	2.46	13.340	3.00	14.128	3.66	14.310	2.85
13.079	2.53	13.183	3.39	13.342	3.03	14.130	3.62	14.314	3.60
13.081	2.75	13.187	3.31			14.131	3.56	14.318	3.51
13.083	3.06	13.191	3.53	14.001	0.99	14.132	3.56	14.323	3.15
13.085	4.11	13.195	3.02	14.006	2.94	14.134	3.67	14.326	1.51
13.087	2.87	13.199	2.77	14.008	3.56	14.136	3.47	14.330	3.49
13.089	2.65	13.203	2.60	14.010	5.83	14.138	3.83		
13.091	2.97	13.207	3.31	14.012	3.50	14.142	3.69		
13.093	2.87	13.211	3.01	14.014	3.51	14.146	3.75		
13.095	2.81	13.215	2.97	14.016	3.28	14.150	3.60		
13.097	3.02	13.219	2.44	14.017	4.19	14.154	4.24		
13.099	2.64	13.223	3.01	14.018	3.13	14.158	2.45		
13.101	2.75	13.227	3.32	14.020	2.89	14.164	1.01		
13.103	2.77	13.231	2.42	14.022	3.45	14.172	3.55		
13.105	2.77	13.235	3.05	14.024	3.55	14.174	3.57		
13.107	2.76	13.237	3.56	14.027	3.55	14.177	3.88		
13.109	2.90	13.239	3.51	14.029	2.63	14.183	3.94		
13.111	2.88	13.241	3.55	14.031	2.03	14.188	2.15		
13.113	2.85	13.243	3.42	14.033	5.05	14.194	1.57		
13.115	3.46	13.245	2.98	14.040	3.65	14.195	1.39		
13.117	2.99	13.247	3.27	14.043	3.53	14.199	1.54		

SIZE STRUCTURE AND GROWTH RATE OF *Euphausia pacifica* OFF THE OREGON COAST[1]

MICHAEL C. SMILES, JR.,[2] AND WILLIAM G. PEARCY[3]

ABSTRACT

Euphausia pacifica (Hansen) off Oregon has a maximum life expectancy of about 1 year. During this time it grows rapidly to a length of 22-24 mm. Furcilia larvae were found throughout the year but were most abundant during the autumn months. The population density and the proportion of juveniles was higher within 25 miles of the coast than in offshore oceanic waters.

Growth rates off Oregon are about twice those previously reported for this species from other regions. Spawning also appears to be later in the year. All these features may be explained by the high primary production which is extended throughout the summer by coastal upwelling and by the lack of wide seasonal fluctuations of water temperatures along the Oregon coast.

Euphausia pacifica is one of the most abundant euphausiids in the North Pacific Ocean. Dense populations are found in Subarctic and Transitional waters (Brinton, 1962a; Ponomareva, 1963) and off the Oregon coast (Hebard, 1966; Osterberg, Pearcy, and Kujala, 1964; Pearcy and Osterberg, 1967).

Euphausiids are important food for many marine carnivores (see Mauchline and Fisher, 1969, and Ponomareva, 1963, for reviews), and *Euphausia pacifica* is no exception. It is preyed upon by salmon (Ito, 1964), baleen whales (Nemoto, 1957, 1959; Osterberg et al, 1964), herring (Ponomareva, 1963), sardine and mackerel (Nakai et al, 1957, as cited by Ponomareva, 1963; Komaki, 1967), rockfish (Pereyra, Pearcy, and Carvey, 1969), pasiphaeid and sergestid shrimp (Renfro and Pearcy, 1966), pandalid shrimp (Pearcy, 1970), and myctophid fishes (Tyler, 1970).

Studies on the growth of several species of euphausiids are reviewed in the monograph by Mauchline and Fisher (1969). Data on the growth and life history of *E. pacifica* are limited. Nemoto (1957) presented some growth data for *E. pacifica* from the Japanese-Aleutian area. Ponomareva (1963), in her study on the distribution and ecology of euphausiids of the North Pacific, estimated the growth of *E. pacifica* from plankton samples collected during the winter and spring. Lasker (1966) determined the growth of *E. pacifica* reared in the laboratory. Preliminary growth rates of *E. pacifica* based on some of our data were also presented by Small (1967).

Because growth rates are needed to understand the ecology and energetics of a species, we undertook this study on the abundance, size structure, and growth rate of *E. pacifica* off Oregon.

COLLECTION METHODS

We made a total of 174 collections using 1-m mouth diameter plankton nets between June 1963 and July 1967 at stations located 15, 25, 45, and 65 miles off Newport, Oreg. In addition, 25 collections were obtained from stations 85-285 miles off Newport. These provided samples of *E. pacifica* for all seasons of the year over a 4-year period. Nets had 0.571-mm mesh openings and were used with a flowmeter placed in

[1] This research was supported by the National Science Foundation (GB-5494) and the Atomic Energy Commission (AT(45-1)-1750; RLO 1750-50).

[2] Formerly, Department of Oceanography, Oregon State University; present address: Biology Department, State University of New York, Farmingdale, N.Y. 11735.

[3] Department of Oceanography, Oregon State University, Corvallis, Oreg. 97331.

Manuscript received September 1970.

the mouth to measure the amount of water filtered.

The first 20 samples were from oblique tows, and the other 154 were from vertical tows. This change to vertical tows was made to ensure equal sampling at all depths throughout a tow. Comparison of the catches of several oblique and vertical tows taken during the same night indicated little difference in the number and size of *E. pacifica* per unit volume filtered.

Because euphausiids may avoid nets in the daytime, all tows were taken during nighttime when visual avoidance would be minimal (Brinton, 1967). This is also a period when *E. pacifica* presumably has migrated into the upper 100 m of the water column. *E. pacifica* captured in several 6-ft Isaacs-Kidd midwater trawls were measured to see if large euphausiids that were possibly avoiding the small vertical meter net could be captured. There was no indication that the maximum size of trawl-caught was larger than meter net-caught euphausiids.

The maximum depth of our tows was usually 200 m. Because Ponomareva (1963) suggested that *E. pacifica* adults inhabit the 200-500-m layer in their second winter and no longer migrate daily to the surface, tows were taken to 1000 m with both the midwater trawls and vertical meter nets. These deeper tows, however, did not contain any larger animals. Twelve vertical meter net samples from depths of 200 m or 1000 m to the surface did not show appreciable differences in size structure. Therefore, we assumed that a representative sample of the *E. pacifica* population was caught in the upper 200 m at night.

The entire plankton sample was preserved at sea in neutralized 10 % Formalin. In the laboratory ashore, all euphausiids were removed from each sample unless the number of euphausiids was large (more than 200 individuals). In such cases the sample was usually divided in half with a Folsom plankton splitter (McEwen, Johnson, and Folsom, 1954), and euphausiids were sorted from only one-half the sample. Males and females were not differentiated.

The length of each individual *E. pacifica* was measured to the nearest 0.1 mm from behind the eye to the posterior margin of the carapace, and each animal was then assigned to a 0.3-mm size-group. Total lengths (from the posterior of the eye to the tip of the telson) were also measured from randomly selected individuals of various lengths to enable comparisons of our data with those of others. A least squares fit of 146 comparisons gave the equation:

$$Y = 2.54\ X + 0.66$$

where Y = total length and X = carapace length. The variance was 248.19. Our measurements are all given as total lengths.

RESULTS

RECRUITMENT AND ABUNDANCE

Although larval *E. pacifica* occurred during almost all months of the year, definite trends in abundance were evident over the 4-year period (Fig. 1). Larvae were usually most abundant between October and December. During some years recruitment began as early as June and was also prominent in the summer months. No major concentrations of larvae were found during winter or spring.

These larval forms of *E. pacifica* were furcilia of about 7 mm or less, agreeing with Boden's (1950) size measurements and description of *E. pacifica* furcilia. Furcilia are found 16-18 days after spawning, usually within the upper 100 m of the water column (Ponomareva, 1963; Brinton, 1967).

Catch curves (Fig. 2) show the average number of different size-groups of *E. pacifica* collected during the entire study. All sizes of *E. pacifica* were much more abundant per m^3 inshore over the continental shelf than in oceanic offshore waters. Individuals larger than 15 mm were rare at station 65 miles or farther offshore. Our finding that larvae were less abundant at offshore than inshore stations agrees with Brinton (1962b), who also noted that *E. pacifica* was more abundant inshore than offshore of California. Thus, despite the wide oceanic distribution of *E. pacifica*, the density of near-

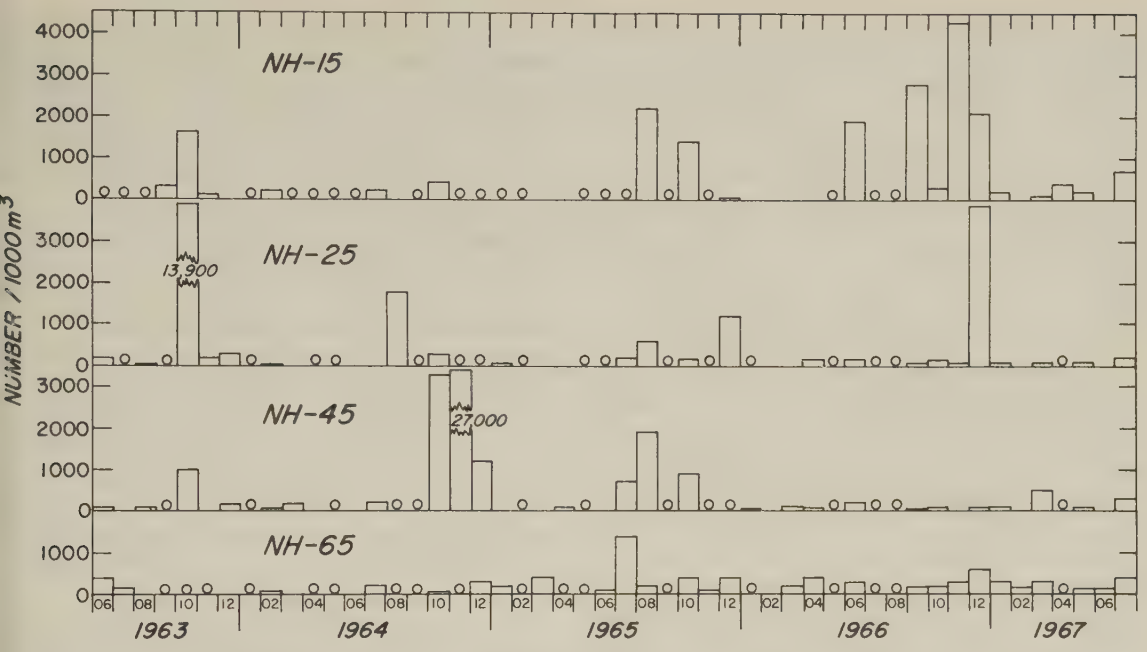
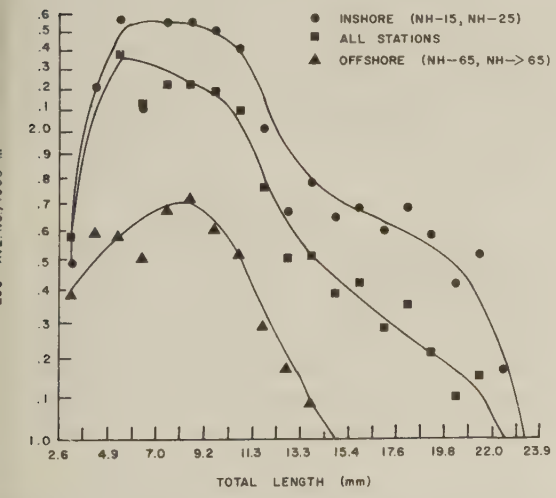


FIGURE 1.—Number of furcilia of *E. pacifica* collected at four stations off Newport, Oregon (NH-15, 25, 45, 65) during 1963-67. "0" indicates no sample taken for that month.



IGURE 2.—Catch curves: the logarithm of the average umber of various sizes of *E. pacifica* caught per 10^3 m^3 or all samples during the study.

hore populations may be considerably higher han offshore populations in the same region. Although inshore tows were generally made only to 50 m and 130 m at the 15- and 25-mile stations respectively because of depth of water, euphausiid abundance at these stations was approximately 10 times greater than at offshore stations. This difference is too great to be explained by the differences in sampling depths even assuming that all euphausiids were concentrated in the upper 50 m at night.

GROWTH RATE

The extended spawning season and variability of catches of *E. pacifica* made interpretation of growth difficult. Three related methods, all based on progressions of size-frequency histograms, generally gave similar growth rates (Table 1) and led to the same conclusion: *E. pacifica* lives for a period of about 1 year and attains a maximum size of about 22-24 mm total length. We tenuously assumed for all these analyses that we sampled the same population, or populations with similar age structures and growth rates.

Two illustrations of growth based on monthly

TABLE 1.—Summary of average growth rate estimated from the progression of modes or means (see Figs. 3 and 4).

Year class	Recruitment month	Number months followed	Growth rates		
			Modes (Fig. 3 for 1965 and 1966 year classes)	Modes (Fig. 4)	Means
			Mm/month		
1963	09	10	1.6	1.9	1.6
1964	10	9	2.0	2.0	1.9
1965	10	8	2.1	2.2	2.0
1966	11	5	2.9	2.5	2.4
1967	03	3	2.6	2.5	2.5

size-frequency histograms of all stations combined (Fig. 3) illustrate the increasing modal lengths between December and June for the 1965 and 1966 year classes. Recruitment of small *E. pacifica* is also obvious during the spring of 1966 and 1967 and also shows a shift in modes with time. The 1963 and 1964 year classes (not shown here) showed similar trends.

A modified histogram plot (Fig. 4) was used to show the data for all 4 years and all 4 stations together. The advantage of this method is that one can follow the main modes of different sizes throughout the 4-year period. A disadvantage is that these plots are distorted by the arbitrary constraints that (1) at least 50 individuals per 10^3 m^3 of water within one size-group had to be present for plotting and (2) concentrations above 5000/10^3 m^3 were plotted only as 5000/10^3 m^3. All of the years represented in Figure 4 show some similarity. The main recruitment pulses are in the fall and summer, and the maximum size attained is approximately 22-24 mm length. After about 1 year, late in the second summer or fall, these large individuals disappeared from our collections. Interestingly, many of the modes that were composed of small euphausiids during the spring and early summer disappeared or were undiscernible by the fall. Either these individuals were subjected to higher mortality than the fall recruits or were transported out of the area. Apparently they made no major contribution to the local adult population.

Average lengths of size modes were also calculated for each collection using the computer techniques described by Hasselblad (1966). The means were generally close to the values for the modal lengths of various collections shown in Figures 3 and 4 and, therefore, are not illustrated here but are given in Table 1.

Our estimates of the growth of *E. pacifica* by all these methods are summarized in Table 1. As expected, estimates are similar for the same year classes. Growth varied from 1.6 to 2.9 mm per month among year classes, averaging about 2.0 mm per month. Growth rates were fastest for young stages. Year-classes 1963 and 1964 had slower average rates (1.6 and 2.0 mm/month) and were calculated over a longer period. Year-classes 1966 and 1967, on the other hand, were represented for the shortest periods of time and had the fastest average rates (2.9 and 2.6 mm/month). This deceleration of growth at the larger sizes is also apparent in Figure 3 where the growth rate from January to March 1966 was about 3.2 mm/month, while from March to June it was about 2.0 mm/month.

Our estimates are biased in several ways. They favored the recruitment pulses of the fall because the smaller modes of young that appeared earlier (June through September) did not comprise a good series of modal sequences. Moreover, the modes and means of the smaller sizes of *E. pacifica* are probably slightly overestimated since catch curves (Fig. 2) indicate escapement from our nets of individuals below 6 mm. This may cause an underestimation of growth rates.

DISCUSSION

Generalized growth curves of *E. pacifica* for three regions of the North Pacific are contrasted in Figure 5. On the basis of bimodal size-frequency distributions of winter and spring samples, Ponomareva (1963) concluded that *E. pacifica* lives for a period of 2 years. She found predominantly 8 and 14-15 mm individuals in the winter and 12-13 mm (her 1-year olds) and 19 mm (2-year olds) in the spring. Off Oregon not only were 12-13 mm individuals rare or absent in spring samples, but also 13-14 mm individuals, the size that Ponomareva would expect to find in the summer and fall, were absent. Moreover, our data, unlike Ponomareva's, show no large seasonal fluctuations of growth with retarded growth of the 13-14 mm sizes

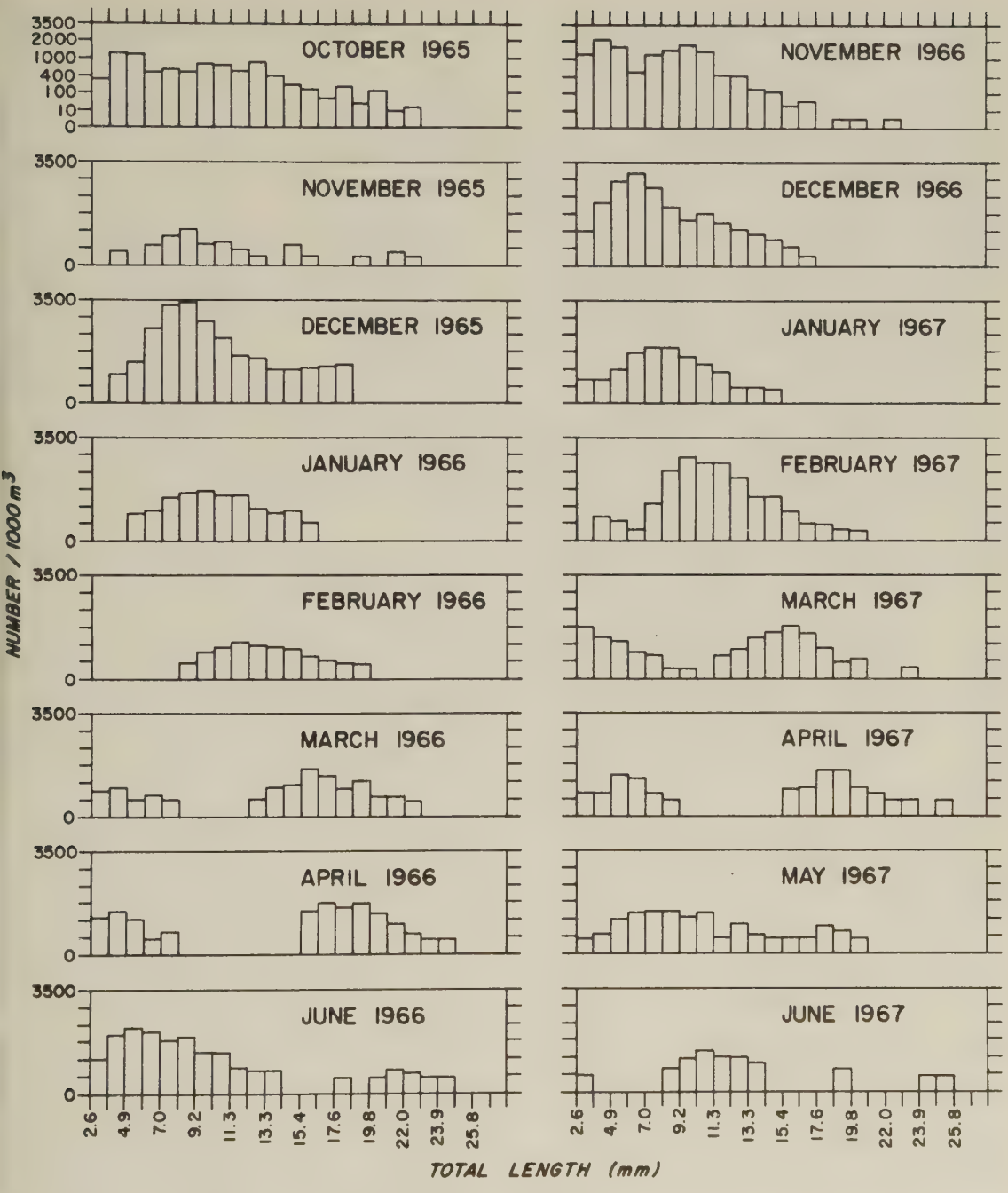


FIGURE 3.—Size frequency distributions of *E. pacifica* from all stations for the 1965 year class (left) and the 1966 year class (right).

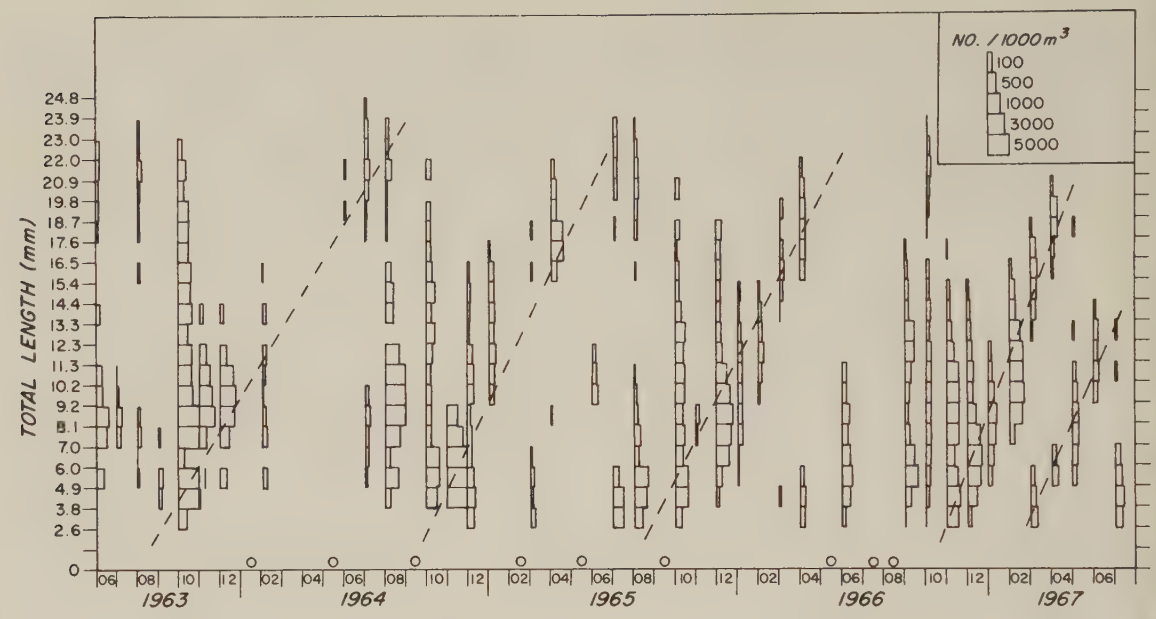


FIGURE 4.—Size frequency histograms for all stations, 1963-67. Dashed lines are an estimate of average growth of individual year classes. "0" indicates no samples for that month.

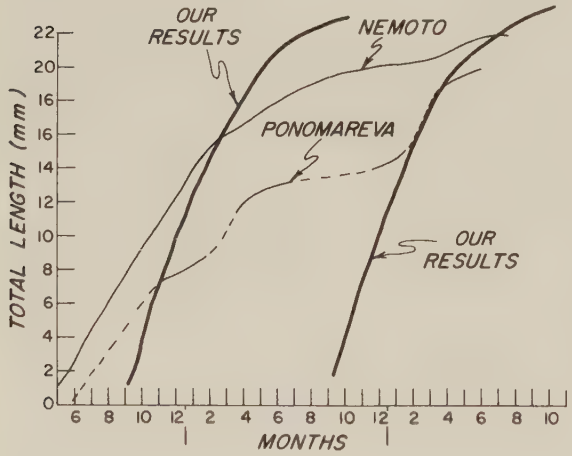


FIGURE 5.—Comparison of generalized growth curves of *E. pacifica*.

in the summer and fall. Nemoto (1957 and personal communication) believes that *E. pacifica* grows rapidly, reaching a length of 17-18 mm after 1 year. Many individuals spawn after 1 year and then may continue to live for another year, reaching a maximum of 22 mm after 2 years. We find no convincing evidence, however, for continuation of large adults through a second year. Large euphausiids disappeared from our samples by the winter (Fig. 4).

Thus our results indicate a faster growth rate and shorter life cycle than those of Ponomareva and Nemoto for the northwestern Pacific but a similar maximum size. Our growth rates off Oregon averaged 0.065 mm/day for the entire life span, about twice those for the other field studies of *E. pacifica*. Maximum rates for rapidly growing juveniles were 0.095 mm/day. These rates are higher than Lasker's (1966) maximum rates for juvenile *E. pacifica* reared in the laboratory, suggesting that growth in nature may exceed "optimal" conditions in the laboratory.

Although our estimates of the growth of *E. pacifica* are higher than previously reported, they approximate the estimates for several other species of euphausiids. A length of about 22 mm after 1 year was also found by Mauchline (1966) for *Thysanoessa raschii;* by Ruud (1936), Mauchline (1960), and Einarsson (1945) for *Meganyctiphanes norvegica;* by Einarsson (1945) for *Thysanopoda acutifrons;* by Ruud

1932), Bargmann (1945), and Marr (1962) for *Euphausia superba;* and by Baker (1959) for *Euphausia triacantha.* Most of these species have a maximum life expectancy of 2 years, reproduce each year, and grow slowly during the winter. Other species are known to have life expectancy of 1 year (Mauchline and Fisher, 1969).

Development, growth, and sexual maturity of the same species of euphausiid are known to vary among geographic populations (Einarsson, 1945; Nemoto, 1957; Ponomareva, 1963; Mauchline and Fisher, 1969). Mauchline and Fisher (1969) stress that this variability is probably directly related to differences in food and temperature. Hence, the rapid growth of *E. pacifica* off Oregon may be related to the high productivity of the region and the lack of large seasonal temperature fluctuations in nearshore waters.

Small, Curl, and Glooschenko[4] report high values for primary productivity in the coastal waters off Oregon. Curl and Small[5] found that standing stocks of chlorophyll-*a* averaged highest inshore and steadily decreased offshore. High production and stocks persist through the summer, the upwelling season, in inshore waters, whereas offshore waters have a typical summer productivity minimum (Anderson, 1964). Note that those seasonal and inshore-offshore gradients in phytoplankton are correlated in time and place with the spawning of *E. pacifica* off Oregon, mostly inshore and protracted over the summer and fall months. Ponomareva (1963) believes that phytoplankton is not only important as food for euphausiid larvae, but also may be necessary in the diet for development of reproductive products of *E. pacifica.*

Water temperatures along the Oregon coast are fairly uniform throughout the year and lack the extremes found along the eastern coasts of continents at similar latitudes. Advection of cool water to the surface (upwelling) during the summer and warm water toward shore during the winter moderates the usual seasonal variations. Pattullo, Burt, and Kulm (1969) observed that the seasonal range of heat content was twice as large offshore as inshore (within 65 miles) of the Oregon coast. The absence of severe winter temperatures may help to explain the rapid growth of *E. pacifica* throughout the year off Oregon. Conversely the slow and seasonally variable growth of *E. pacifica* found by Ponomareva (1963) was in the Far Eastern Seas of Asia where temperatures are often lower and where thermal variations are greater. The fact that *E. pacifica* is the only widespread euphausiid that spawns in the summer, when the phytoplankton bloom was almost over, indicates that this boreal species may be poorly adapted to the cold marginal Far Eastern Seas (Ponomareva, 1963).

The main pulses of larvae, hence spawning, of *E. pacifica* were in the fall, and not in the spring and summer as found by Ponomareva (1963), Nemoto (1957) off Japan, and Barham (1957) in Monterey Bay, Calif. Brinton (personal communication) notes larval recruitment throughout the year off Southern California. The later spawning off Oregon, like the rapid growth, may again be related to the prolonged production cycle caused by upwelling off Oregon and the moderate fall and winter water temperatures.

[4] L. F. Small, H. Curl, Jr., and W. A. Glooschenko. Seasonal primary production in a region of upwelling. II. Effects of solar radiation and upwelling on daily production. Unpublished MS.

[5] H. Curl, Jr., and L. F. Small. MS.

ACKNOWLEDGMENTS

We are grateful to J. Mauchline for his suggestions and to T. Nemoto for providing his growth curve for *E. pacifica.*

LITERATURE CITED

ANDERSON, GEORGE C.
1964. The seasonal and geographic distribution of primary productivity off the Washington and Oregon coasts. Limnol. Oceanogr. 9(3): 284-302.

BAKER, A. DE C.
1959. The distribution and life history of *Euphausia triacantha* Holt and Tatersall. Discovery Rep. 29: 309-340.

BARGMANN, HELENE E.
1945. The development and life-history of adolescent and adult krill, *Euphausia superba.* Discovery Rep. 23: 103-176.

BARHAM, ERIC GEORGE.
1957. The ecology of sonic scattering layers in the Monterey Bay area, California. Ph.D. Thesis, Stanford Univ. 192 p. Univ. Microfilms, Ann Arbor, Mich. Publ. 21, 564.

BODEN, BRIAN P.
1950. The post-naupliar stages of the crustacean *Euphausia pacifica*. Trans. Amer. Microsc. Soc. 69(4): 373-386.

BRINTON, EDWARD.
1962a. The distribution of Pacific euphausiids. Bull. Scripps Inst. Oceanogr. Univ. Calif. 8(12): 51-270.
1962b. Variable factors affecting the apparent range and estimated concentrations of euphausiids in the North Pacific. Pac. Sci. 16(4): 374-408.
1967. Vertical migration and avoidance capability of euphausiids in the California Current. Limnol. Oceanogr. 12(3): 451-483.

EINARSSON, HERMANN.
1945. Euphausiacea. 1. North Atlantic species. Dana Rep. Carlsberg Found. 27, 1-185.

HASSELBLAD, VICTOR.
1966. Estimation of parameters for a mixture of normal distributions. Technometrics 8(8): 431-444.

HEBARD, J. F.
1966. Distribution of Euphausiacea and Copepoda off Oregon in relation to oceanic conditions. Ph.D. Thesis, Oregon State Univ., Corvallis. 85 p.

ITO, JUN.
1964. Food and feeding habit of Pacific salmon (genus *Oncorhynchus*) in their oceanic life. Bull. Hokkaido Reg. Fish. Lab. 29: 85-97.

KOMAKI, YUZO.
1967. On the surface swarming of euphausiid crustaceans. Pac. Sci. 21(4): 433-448.

LASKER, REUBEN.
1966. Feeding, growth, respiration, and carbon utilization of a euphausiid crustacean. J. Fish. Res. Bd. Can. 23(9): 1291-1317.

MARR, JAMES.
1962. The natural history and geography of the Antarctic krill (*Euphausia superba* Dana). Discovery Rep. 32: 33-464.

MAUCHLINE, J.
1960. The biology of the euphausiid crustacean, *Meganyctiphanes norvegica* (M. Sars). Proc. Roy. Soc. Edinburgh, Sect. B. (Biol.) 67: 141-179.
1966. The biology of *Thysanoessa raschii* (M. Sars), with a comparison of its diet with that of *Meganyctiphanes norvegica* (M. Sars). *In* Harold Barnes (editor), Some contemporary studies in marine science, p. 493-510. George Allen and Unwin Ltd., London.

MAUCHLINE, JOHN, AND LEONARD R. FISHER.
1969. The biology of euphausiids. *In* Frederick S. Russell and Maurice Yonge (editors), Advances in marine biology. Vol. 7, 454 p.

MCEWEN, G. F., M. W. JOHNSON, AND TH. R. FOLSOM.
1954. A statistical analysis of performance of the Folsom plankton sample splitter, based on test observations. Arch. Meteorol. Geophys. Bioklimatol., Ser. A. 7: 502-527.

NEMOTO, TAKAHISA.
1957. Foods of baleen whales in the northern Pacific. Sci. Rep. Whales Res. Inst. 12: 33-90.
1959. Food of baleen whales with reference to whale movements. Sci. Rep. Whales Res. Inst. 14: 149-290.

OSTERBERG, CHARLES, WILLIAM PEARCY, AND NORMAN KUJALA.
1964. Gamma emitters in a fin whale. Nature (London) 204(4962): 1006-1007.

PATTULLO, JUNE G., WAYNE V. BURT, AND SALLY A. KULM.
1969. Oceanic heat content off Oregon: Its variations and their causes. Limnol. Oceanogr. 14(2): 279-287.

PEARCY, WILLIAM G.
1970. Vertical migration of the ocean shrimp, *Pandalus jordani*: A feeding and dispersal mechanism. Calif. Fish Game 56(2): 125-129.

PEARCY, WILLIAM G., AND CHARLES L. OSTERBERG.
1967. Depth, diel, seasonal, and geographic variations in zinc-65 of midwater animals of Oregon. Int. J. Oceanol. Limnol. 1(2): 103-116.

PEREYRA, WALTER T., WILLIAM G. PEARCY, AND FORREST E. CARVEY, JR.
1969. *Sebastodes flavidus*, a shelf rockfish feeding on mesopelagic fauna, with consideration of the ecological implications. J. Fish. Res. Bd. Can. 26(8): 2211-2215.

PONOMAREVA, LARISA NATAL'EVNA.
1963. Euphausiids of the North Pacific, their distribution and ecology. Akad. Nauk SSSR Inst. Okeanol. (Translated by Israel Program for Scientific Translations, Jerusalem 1966, IPST catalog no. 1368, 154 p.)

RENFRO, WILLIAM C., AND WILLIAM G. PEARCY.
1966. Food and feeding apparatus of two pelagic shrimps. J. Fish. Res. Bd. Can. 23(12): 1971-1975.

RUUD, JOHN T.
1932. On the biology of southern Euphausiidae. Hvalradets Skr. 2. 105 p.
1936. Euphausiacea. Rep. Dan. Oceanogr. Exped. 1908-1910 Mediter. Adjacent Seas 2D6(Biol.), 86 p.

SMALL, LAWRENCE F.
1967. Energy flow in *Euphausia pacifica*. Nature (London) 215(5400): 515-516.

TYLER, H. R., JR.
1970. The feeding habits of three species of lanternfishes (Myctophidae) off Central Oregon. Master's Thesis, Oregon State Univ., Corvallis. 64 p.

ESTIMATING PHYTOPLANKTON PRODUCTION FROM AMMONIUM AND CHLOROPHYLL CONCENTRATIONS IN NUTRIENT-POOR WATER OF THE EASTERN TROPICAL PACIFIC OCEAN[1,2]

WILLIAM H. THOMAS[3] AND ROBERT W. OWEN, JR.[4]

ABSTRACT

Previous work has shown that nitrogen is the limiting nutrient in poor (nitrate-free) water in the eastern tropical Pacific Ocean and has suggested that ammonium is the principal nitrogen source for phytoplankton in this water. Enrichment and uptake experiments with various concentrations of ammonium have provided values for the half-saturation constant, K_s, and the maximum growth rate, μ_{max}, which can be used to calculate actual growth rates with the hyperbolic model relating growth rate to limiting nutrient concentration. At two stations, growth rates calculated from ammonium concentration agreed well with those calculated from chlorophyll and ^{14}C production, and the hyperbolic equation could be combined with that using production and chlorophyll to calculate production alone. In this paper calculated production rates are compared with those observed from ^{14}C uptake measurements for a number of EASTROPAC cruises. The regression between calculated production and observed production is highly significant and the slope is close to 1.0, indicating reasonable agreement, particularly when all of the errors in the calculation, especially in K_s, are considered. The results suggest rather close control of phytoplankton production by the limiting nutrient, ammonium, in these near-surface, nutrient-poor waters.

This paper describes how concentrations of a limiting nutrient in sea water and some measure of the standing crop of phytoplankton can be used to estimate phytoplankton production. Estimated production is compared with observed ^{14}C production, and the two sets of values are shown to agree reasonably well when all the errors in the estimation are considered.

The EASTROPAC Expedition series has delineated particularly well areas that are rich in nutrients and that are nutrient-poor in the eastern tropical Pacific Ocean. Rich areas include the Peru Current, the Costa Rica Dome, and an area of equatorial upwelling extending across the EASTROPAC area (from the American coast to long 119° W). Poor areas lie to the north and south of the equatorial upwelling zone and to the west of the Peru Current and Costa Rica Dome. Rich and poor near-surface waters were mapped in previous papers (Thomas, 1969, 1970b) and will be shown in detail in the EASTROPAC Atlas (Thomas, unpublished data). Nutrient values for rich and poor water are also given in Table 1 of Thomas (1970a).

Corresponding areal and seasonal changes in the phytoplankton production in this region have been observed and attributed in part to mechanisms of nutrient supply (Owen and Zeitzschel, 1970). No accounting has been possible, however, for the variations observed within the nutrient-poor surface layer of the region.

Near-surface water in poor areas is especially low in nitrate-nitrogen; this nutrient is generally not detectable (<0.1 μg-at./liter). Ammonium-N is present in concentrations ranging up to 1 μg-at./liter and organic nitrogen can reach

[1] Contribution from the Scripps Institution of Oceanography.

[2] This work was part of the research of the STOR (Scripps Tuna Oceanography Research) Program. It is also a result of the EASTROPAC Expedition, a cooperative study of the biological, chemical, and physical oceanography of the eastern tropical Pacific Ocean. The work was supported by National Science Foundation Grant No. GB-8618 to the senior author, and by contracts #14-17-0007-963 and #14-17-0007-989 between the Bureau of Commercial Fisheries (now the National Marine Fisheries Service) and the Institute of Marine Resources.

[3] Institute of Marine Resources, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, Calif. 92037.

[4] National Marine Fisheries Service Fishery-Oceanography Center, La Jolla, Calif. 92037.

Manuscript received September 1970.

concentrations of 17 μg-at./liter, but this latter nitrogen source is probably not utilized by phytoplankton (Thomas, Renger, and Dodson, in press).

Prior to EASTROPAC (pre-1967) low nitrate/phosphate ratios in tropical Pacific poor water suggested that nitrogen was a limiting nutrient although ratios were increased when ammonium was included along with nitrate, and it was suggested that this latter nutrient alleviated N deficiency (Thomas, 1966).

Recent EASTROPAC enrichment experiments provided direct evidence for N limitation. Phytoplankton growth occurred in experiments where nutrients were added singly to sea water samples only with N addition, and if N was deleted from an otherwise complete enrichment, little or no growth resulted (Thomas, 1969, 1970b). The fact that photosynthetic assimilation ratios were only slightly (but significantly) decreased in poor water as compared with rich water testified further to the alleviation and control of deficiency by ammonium (Thomas, 1970a).

Having established which nutrient is commonly limiting, one can use a quantitative nutrient requirement in an appropriate mathematical model to estimate growth rates (production) from concentration of the limiting nutrient. Recent work (Caperon, 1967; Dugdale, 1967) indicates that the best model is hyperbolic:

$$\mu = \mu_{max} \left(\frac{S}{K_s + S} \right) \quad (1)$$

where μ is the phytoplankton specific growth rate, μ_{max} is the maximum rate which is unlimited by low nutrient concentration, S is a measured limiting nutrient concentration in sea water, and K_s is the "half-saturation constant" —a nutrient concentration that supports a rate equal to $\mu_{max}/2$. This equation is equivalent to the Michaelis-Menton formulation for enzyme kinetics and was first applied to bacterial growth rates by Monod (1942). Many biological processes follow the hyperbolic model and since growth is the result of a series of coupled enzymatic reactions, the hyperbolic model is the model of choice.

A previous paper (Thomas, 1970b) provides information on μ_{max} and K_s (for ammonium) from which μ can be calculated. To obtain these values we enriched samples of nutrient-poor Pacific sea water from a depth of 10 m with a complete mixture of non-nitrogenous nutrients to which various concentrations of ammonium were added. The samples were then incubated in natural light approximating the intensity that would be found at 10 m depth. Growth was estimated by successive daily measurements of *in vivo* chlorophyll (Lorenzen, 1966) in each treatment, and rates integrated over a daily period were calculated from the maximum increases in chlorophyll. These rates were plotted against ammonium concentrations to fit a hyperbolic model and values of K_s and μ_{max} were obtained from the plot. These values and their 95% confidence limits are given in Table 1 for two such experiments. K_s values can also be determined from uptake experiments since recent work has shown that K_s values for growth and uptake are equivalent (Eppley and Thomas, 1969). Also included in Table 1 are uptake K_s values obtained by MacIsaac and Dugdale (1969) for nutrient-poor tropical Pacific water. Their values for V_{max}, the maximum uptake rate, are not equivalent to μ_{max} and thus are not included

TABLE 1.—Rate parameters for growth and uptake on ammonium in nutrient-poor tropical Pacific sea water.

Cruise	Station	K_s (μM)	95 percent limits	μ_{max} (Doublings/day)	95 percent limits	Reference
EASTROPAC 76	007	1.68	± 3.28	1.12	± 0.83	Thomas (1970b)
EASTROPAC 76	173	1.47	± 0.91	1.22	± 0.27	Thomas (1970b)
Thompson 26	15	0.10	--	--	--	MacIsaac and Dugdale (1969)
Thompson 26	36	0.55	--	--	--	MacIsaac and Dugdale (1969)
Te Vega 13	651-a	0.62	--	--	--	MacIsaac and Dugdale (1969)
Mean values		0.88		1.17		
95 % limits of mean		1.33		0.14		

in Table 1. It will be noted that confidence limits for K_s values in given experiments are large as is the confidence limit for the mean of all five values which is used in subsequent calculations (see Results and Discussion). This can be attributed to lack of precision in measuring either growth or uptake; even in controlled experiments with laboratory cultures, K_s values are imprecise (Eppley, Rogers, and McCarthy, 1969; Eppley and Thomas, 1969).

The integrated daily growth rate, μ, can also be calculated from ^{14}C production estimates and chlorophyll concentrations using the following equation:

$$\mu = \frac{3.32\,[\log_{10}(R \cdot \text{chl} + \text{Prod}) - \log_{10}(R \cdot \text{chl})]}{1 \text{ day}} \quad (2)$$

as has been done for laboratory cultures by Thomas (1964) and McAllister, Shah, and Strickland (1964). In this equation R is the carbon/chlorophyll ratio; $R \cdot$ chl thus is the standing stock of phytoplankton carbon. The constant 3.32 converts logarithms to the base 10 to logarithms to the base 2 and allows μ to be expressed as doublings of phytoplankton carbon per day.

In the previous paper (Thomas, 1970b), μ calculated from ammonium (equation 1) was compared with μ calculated from ^{14}C production and chlorophyll (equation 2) for the two EASTROPAC stations where K_s and μ_{max} were determined from enrichment experiments. At station 76.007, μ calculated from ammonium was 0.385 doublings/day while that calculated from ^{14}C uptake and chlorophyll was 0.365 doublings/day. At station 76.173 both values were identical—0.276 doublings/day. For the calculation we used an R value of 98, that found by Eppley (1968) for nitrate-free water off La Jolla.

This excellent agreement suggested that we could set equation (1) equal to equation (2) and solve for production as a function of ammonium and chlorophyll using K_s and μ_{max} as constants. The new equation thus derived is

$$\text{Prod} = \text{chl} \cdot R \left[\text{antilog}\left(\frac{\mu_{max}}{3.32} \cdot \frac{S}{K_s + S}\right) - 1 \right] \quad (3)$$

This expression allows a direct comparison calculated and measured ^{14}C production (see Results and Discussion).

METHODS

Methods for determining K_s and μ_{max} were given previously (Thomas, 1970b; MacIsaac and Dugdale, 1969)—see also the previous section. Chlorophyll and production samples were taken from the depth of the 50 % light level, which was always in the upper mixed layer and varied from 9 to 16 m. This depth was determined by multiplying the depth at which the Secchi disc disappeared by 0.38. This factor employs the assumption that the Secchi disc disappears at 16 % of surface light intensity (Strickland, 1958).

Chlorophyll was determined in these samples by filtration on glass fiber filters, followed by 90 % acetone extraction of the filters, and measurement of fluorescence of the extract (Yentsch and Menzel, 1963; Holm-Hansen, Lorenzen, Holmes, and Strickland, 1965) using equations developed by Lorenzen (1966).

Simulated *in situ* production was measured by adding 20 μc $Na_2{}^{14}CO_3$ solution to the samples (Steemann Nielsen, 1952) and incubating them in a tubular shipboard incubator space in which natural light intensity was attenuated to 50 % of that incident. Incubation was started at noon and continued until sunset at sea surface temperature. Following incubation the samples were filtered through HA Millipore®[5] filters and their radioactivity assayed ashore by G-M counting of the filters. The ^{14}C solution was standardized by liquid scintillation counting and the efficiency of the G-M counter for these filters was determined by combusting some of these and measuring the evolved $^{14}CO_2$ with an ionization chamber. Daily uptake was determined by multiplying the activity by 2; we also corrected for the isotope effect by multiplying by 1.05. Darkened samples were incubated with illuminated samples and dark uptake was subtracted from light uptake. No cor-

[5] The use of trade names is merely to facilitate descriptions: no endorsement is implied.

rections for respiration by phytoplankton were made.

Ammonium was measured ashore in frozen samples from a depth of 10 m by the method of Richards and Kletsch (1964). Some labile amino-N which is probably available to phytoplankton is measured along with ammonium by this method.

RESULTS AND DISCUSSION

For the comparison of calculated and measured ^{14}C production, we have used samples from 10 m incubated at light intensities approximating those at 10 m to determine K_s and μ_{max}, and actual ^{14}C values from the 50% light level. We did this so that light intensities would not be a factor in the comparison—that is, light was presumed to be at saturating intensities but not inhibitory, which would be the case if surface samples had been incubated in the growth experiments and compared with surface production.

Ammonium was not determined at all production stations, and we selected those production values where data were available for

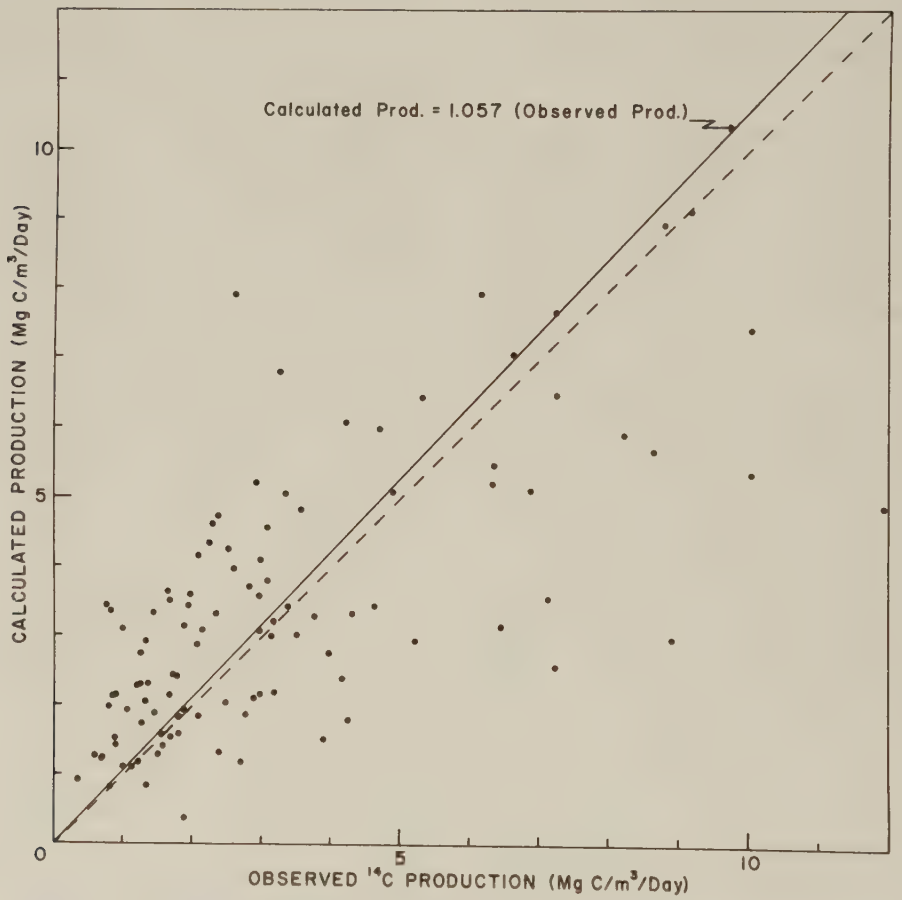


FIGURE 1.—Phytoplankton production calculated from ammonia and chlorophyll concentrations at 10 m compared with simulated *in situ* ^{14}C production at the 50 % light level in northerly nutrient-poor water in the eastern tropical Pacific Ocean. The dashed line is the regression that would be expected if agreement between the two sets of production values were perfect.

ammonium and where nitrate was undetectable. One hundred and five such production stations were available from 10 EASTROPAC cruises in this nutrient-poor water.

Production calculated from equation 3 is compared with measured ^{14}C production in Figure 1. There is a highly significant ($P<.01$) relationship between the two sets of values. The slope of the regression line is 1.057, which is very near to the value 1.0 which would be expected if agreement were perfect. Nevertheless, there is a large amount of scatter in the values of Figure 1; that is, the calculation overestimates in some cases and underestimates in others.

TABLE 2.—Errors in the calculation of production.

Parameter	Standard errors	Reference
Chlorophyll	± 12%	Holmes, Schaefer, and Shimada (1958)
R	± 17%	Eppley (1968)
μ_{max}	± 6%	Table 1 (this paper)
S	± 5%	Richards and Kletsch (1964)
K_s	± 76%	Table 1 (this paper)
Total	± 79%	
95% confidence limits	± 152%	

Errors in the values used in the calculation are given in Table 2. To figure total error these have been converted to variances and summed. The 95% confidence limit shows that any calculated production value can vary by ± 1.5 fold. Thus, one would expect quite a large scatter in Figure 1.

Most of the error is in K_s. When only the K_s values of Thomas (1970b) are used the calculation generally underestimates the observed ^{14}C production. Use of the mean of the K_s values of MacIsaac and Dugdale (1969) results in an overestimation. Since there is no reason to doubt either set of K_s values, we have used the overall mean K_s from Table 1. In applying this method to any other nutrient-limited waters, it would be well to obtain several values of K_s so that the error due to lack of precision in measuring K_s can be recognized.

Part of the scatter in Figure 1 may also be due to the fact that the parameter K_s is species—and temperature—dependent (Eppley, Rogers, and McCarthy, 1969) and that variations in species composition of the crop or slight variations in temperature may have affected the calculation. The parameters μ_{max} and R are also probably dependent upon the species composition of the crop and on temperature. Because of these factors, which are unknown, it is perhaps surprising that the relationship between calculated and observed production is so good when constant values of K_s, μ_{max}, and R are used.

This evidence supports the hypothesis that phytoplankton production in the upper mixed layer is controlled by the limiting nutrient, ammonium, and shows that the hyperbolic model describes this control very well. In this latter connection it should be noted that if a linear model having a term "S/S_{max}" in equation 3 (where S_{max} is that concentration supporting a maximum growth rate and which has a value near 10.0 μM from the data of Thomas, 1970b) is used rather than the term "$S/(K_s + S)$," the calculation very much underestimates the ^{14}C production. The linear model was used previously by Riley (1963) and Steele (1958) but should now be considered obsolete in view of more recent work using the hyperbolic model.

ACKNOWLEDGMENTS

We appreciate the assistance of many persons in gathering these data. Ammonium analyses were performed by Mr. Edward Renger, and Mrs. Anne Dodson aided in the determination of μ_{max} and K_s. Sampling and incubation for production measurements and determination of chlorophyll concentrations were carried out by the following: Messrs. Tapuni Mulitauaopele, Michael Kruse, David Justice, James McCarthy, Lawrence Klapow, David Judkins, Gerald Johnson, Eric Forsbergh, and Jack Metoyer. Dr. Bernt Zeitzschel and Mr. Michael Kruse helped to process and edit the ^{14}C and chlorophyll data. Most of these data were collected aboard the NMFS vessel *David Starr Jordan* and we appreciate the assistance of Capt. C. W. Forster and his crew.

LITERATURE CITED

CAPERON, JOHN.
1967. Population growth in micro-organisms limited by food supply. Ecology 48(5): 715-722.

DUGDALE, R. C.
1967. Nutrient limitation in the sea: Dynamics, identification, and significance. Limnol. Oceanogr. 12(4): 685-695.

EPPLEY, RICHARD W.
1968. An incubation method for estimating the carbon content of phytoplankton in natural samples. Limnol. Oceanogr. 13(4): 574-582.

EPPLEY, RICHARD W., AND WILLIAM H. THOMAS.
1969. Comparison of half-saturation constants for growth and nitrate uptake of marine phytoplankton. J. Phycol. 5(4): 375-379.

EPPLEY, RICHARD W., JANE N. ROGERS, AND JAMES J. MCCARTHY.
1969. Half-saturation constants for uptake of nitrate and ammonium by marine phytoplankton. Limnol. Oceanogr. 14(6): 912-920.

HOLMES, R. W., M. B. SCHAEFER, AND B. M. SHIMADA.
1958. SCOPE measurements of productivity, chlorophyll "a", and zooplankton volumes. *In* Robert W. Holmes, and other members of the Scripps Cooperative Oceanic Productivity Expedition, Physical, chemical, and biological oceanographic observations obtained on Expedition SCOPE in the eastern tropical Pacific, November-December 1956, p. 59-68. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 279.

HOLM-HANSEN, OSMUND, CARL J. LORENZEN, ROBERT W. HOLMES, AND JOHN D. H. STRICKLAND.
1965. Fluorometric determination of chlorophyll. J. Cons. Cons. Perma. Int. Explor. Mer 30(1): 3-15.

LORENZEN, CARL J.
1966. A method for the continuous measurement of *in vivo* chlorophyll concentration. Deep-Sea Res. Oceanogr. Abstr. 13(2): 223-227.

MACISAAC, J. J., AND R. C. DUGDALE.
1969. The kinetics of nitrate and ammonia uptake by natural populations of marine phytoplankton. Deep-Sea Res. Oceanogr. Abstr. 16(1): 45-57.

MCALLISTER, C. D., N. SHAH, AND J. D. H. STRICKLAND.
1964. Marine phytoplankton photosynthesis as a function of light intensity: A comparison of methods. J. Fish. Res. Bd. Can. 21(1): 159-181.

MONOD, J.
1942. Recherches sur la croissance des cultures bacterienne. Hermann et Cie, Paris.

OWEN, R. W., AND B. ZEITZSCHEL.
1970. Phytoplankton production: seasonal change in the oceanic eastern tropical Pacific. Mar. Biol. 7(1): 32-36.

RICHARDS, FRANCIS A., AND RICHARD A. KLETSCH.
1964. The spectrophotometric determination of ammonia and labile amino compounds in fresh and sea water by oxidation to nitrite. *In* Yasuo Miyake and Tadashiro Koyama (editors), Ken Sugawara festival volume; recent researches in the fields of hydrosphere, atmosphere and nuclear geochemistry, p. 65-81. Maruzen Company, Ltd., Tokyo.

RILEY, G. A.
1963. Theory of food-chain relations in the ocean. *In* M. N. Hill (editor), The sea, Vol. 2, p. 438-463. Interscience Publishers, New York.

STEELE, J. H.
1958. Plant production in the northern North Sea. Scot. Home Dep., Mar. Res. 7, 36 p.

STEEMANN NIELSEN, E.
1952. The use of radio-active carbon (C^{14}) for measuring organic production in the sea. J. Cons. Cons. Perma. Int. Explor. Mer 18(2): 117-140.

STRICKLAND, J. D. H.
1958. Solar radiation penetrating the ocean. A review of requirements, data and methods of measurement, with particular reference to photosynthetic productivity. J. Fish. Res. Bd. Can. 15(3): 453-493.

THOMAS, WILLIAM H.
1964. An experimental evaluation of the C^{14} method for measuring phytoplankton production, using cultures of *Dunaliella primolecta* Butcher. U.S. Fish Wild. Serv., Fish. Bull. 63(2): 273-292.
1966. Surface nitrogenous nutrients and phytoplankton in the northeastern tropical Pacific Ocean. Limnol. Oceanogr. 11(3): 393-400.
1969. Phytoplankton nutrient enrichment experiments off Baja California and in the eastern equatorial Pacific Ocean. J. Fish. Res. Bd. Can. 26(5): 1133-1145.
1970a. On nitrogen deficiency in tropical Pacific oceanic phytoplankton: Photosynthetic parameters in poor and rich water. Limnol. Oceanogr. 15(3): 380-385.
1970b. Effect of ammonium and nitrate concentration on chlorophyll increases in natural tropical Pacific phytoplankton populations. Limnol. Oceanogr. 15(3): 386-394.

THOMAS, W. H., E. H. RENGER, AND ANNE N. DODSON.
In press. Near-surface organic nitrogen in the eastern tropical Pacific Ocean. Deep-Sea Res. Oceanogr. Abstr.

YENTSCH, CHARLES S., AND D. W. MENZEL.
1963. A method for the determination of phytoplankton chlorophyll and phaeophytin by fluorescence. Deep-Sea Res. Oceanogr. Abstr. 10(3): 221-231.

ECOLOGICAL EFFICIENCY OF A PELAGIC MYSID SHRIMP; ESTIMATES FROM GROWTH, ENERGY BUDGET, AND MORTALITY STUDIES[1]

ROBERT I. CLUTTER[2] AND GAIL H. THEILACKER[3]

ABSTRACT

The net ecological efficiency (yield/assimilated) of a population of *Metamysidopsis elongata* (Crustacea, Mysidacea) is estimated to be 32 %. The gross ecological efficiency (yield/ingested) is probably between 19 % and 29 %.

Energy use by the field population was calculated from estimates of age specific natural mortality rates and data on growth, molting, reproduction, and respiration. Average growth and molting rates were determined by rearing the mysids in the laboratory. Size specific fecundity was determined from field and laboratory observations. The calorie contents of the mysids, their molts, eggs and larvae were estimated by bomb calorimetry and in part from biochemical composition. The energy used in metabolism was calculated from size specific respiration and data on body composition.

Biological systems are organized by the flow of energy. Trophic structure, numbers of steps in food chains, and numbers of conjunctions in food webs depend on the amount of energy passed through populations to other populations. Energy units provide a means of expressing productivity in terms common to all organisms.

The energy produced in the breakdown of biomass by organisms is stored as chemical energy in the pyrophosphate bonds of adenosine triphosphate (Morowitz, 1968). The overall thermodynamic efficiency of this process is similar in all animals, about 60 to 70 % according to Krebs and Kornberg (1957). It has been suggested (e.g. Slobodkin, 1961, 1962) that the efficiency of energy transfer between populations of animals is also fairly constant. This efficiency is necessarily of lower order because, for example, there are losses involved in synthesizing macromolecules, in continually resynthesizing proteins that undergo thermal denaturation, in transforming foodstuff energy into work energy (about 65 % efficiency), and in the degradation of energy during the performance of work. All energy that passes through a population is either lost as heat or passes on to another trophic level. If one assumes that all mortality is caused by predation, the gross ecological efficiency (Phillipson, 1966) of energy transfer through that population is the ratio of the energy yield in mortality to the energy ingested.

Through laboratory studies of growth, molting, reproduction, respiration, body composition, and energy content, we have constructed an energy budget for the pelagic mysid shrimp *Metamysidopsis elongata* (Holmes). Various aspects of the distribution, behavior, and population biology of this species have been described by Clutter (1967, 1969) and Fager and Clutter (1968). The energy budget data, together with estimates of natural population mortality rates, are used to estimate net and gross ecological efficiencies for the field population.

GROWTH AND DEVELOPMENT

Metamysidopsis elongata is a member of the Mysidae, a family that is ubiquitous and often very abundant in most of the neritic zones of the world ocean. This species is free-swimming and occurs in shoals and swarms just above the sand bottom in areas where surf is common

[1] This research was supported in part by NSF Grant GB 7132.

[2] Formerly of National Marine Fisheries Service Fishery-Oceanography Center, La Jolla, Calif. 92037.

[3] National Marine Fisheries Service Fishery-Oceanography Center, La Jolla, Calif. 92037.

Manuscript received September 1970.

(Clutter 1967, 1969).

As is characteristic of mysids, the eggs and larvae are held by the oostegites (brood pouch) of the adult females until they develop into juveniles that are similar in form to the adults. The juveniles grow by shedding their exoskeletons (ecdysis) at intervals that become progressively longer until they reach maturity. Males and females develop distinguishable morphological features during the period of rapid growth prior to maturity. Growth becomes progressively slower after maturity. Although there is no evidence that death occurs because of physiological aging, the maximum age observed was about 9 months. Most animals survive less than 3 months in the natural environment . We assume that most of the natural mortality is caused by predation, especially by fishes.

Some growth experiments have been reported for other species of Mysidae. Blegvad (1922) determined the growth rates of a few individuals of *Mysis inermis* from first stage juveniles through early maturity. Nouvel and Nouvel (1939) made disjunct determinations of time between molt stages for some size groups of *Praunus flexuosis*. Nair (1939) observed the time sequence in the egg and larva development of *Mesopodopsis orientalis*, determined the size and age at liberation, and noted the size at sexual maturity of males and females. In his review of growth in some marine Crustacea, Kurata (1960) presented the results of growth studies made by Ishikawa and Oshima on *Neomysis japonica* and by Matsudaira et al. on *Gastrosaccus vulgaris*. Mauchline (1967) maintained adult *Schistomysis spiritus* in the laboratory, estimated the time they take to attain sexual maturity, and estimated the minimum incubation time. Considering differences between species, sizes, and environmental temperatures, these reported patterns of development and size increase per molt are compatible with the results of our study.

CULTURE METHODS

Experimental animals were collected during the day from the middle of their habitat with nets (Clutter, 1965; Fager, Flechsig, Ford, Clutter, and Ghelardi, 1966). They were placed in large (20-50 liter), opaque plastic containers with covers and transported to the laboratory within 1 to 2 hr after the time of capture.

The culture methods were about the same as those described by Lasker and Theilacker (1965) for euphausid shrimps. Individual animals were placed in rectangular clear plastic containers in about 500 ml of sea water. The small containers were partly immersed in trays of running sea water. Since the running sea water was pumped continuously into the aquarium from midwater offshore, within the *Metamysidopsis* habitation zone, the laboratory temperatures (14°-20° C) were about the same as those that the animals would have experienced in their natural environment.

Animals of both sexes and of several sizes were selected for the experiments. Young juveniles were procured by placing pregnant females in containers and recovering the young on the day following their release from the brood pouch, which occurred at night. These young were then placed in separate containers. To determine the incubation time, i.e. the time from fertilization of the eggs to release from the brood pouch as juveniles, pregnant females with known times of fertilization were placed in individual containers so that larval development could be observed.

Mysids of all ages were fed freshly hatched nauplius larvae of brine shrimp, (*Artemia salina*). Twice each week the mysids were removed while their containers were emptied of excess food and cleaned with hot fresh water followed by a sea water rinse. They were then provided with excess quantities of fresh nauplii in clean sea water.

The containers were examined every day for the presence of molts or, occasionally, carcasses. The molts and carcasses were removed and placed individually in small vials of 5 % Formalin for subsequent microscopical examination and measurement.

OOGENESIS AND INCUBATION

Since *Metamysidopsis* has a transparent cara-

pace and body wall, it is possible to observe the late stages of oogenesis in live animals without dissecting them. The ovary (cf. Nair, 1939, for description) is situated in the interspace between the alimentary canal and the pericardial floor. Its most obvious feature is the pair of larger tubes that lay side by side. It is in these tubes that the eggs to be extruded into the brood pouch are invested with yolk. The process of yolk formation takes about a week in *Metamysidopsis* and is completed just before the female molts and copulates. By observing the ova in these tubes it is possible to estimate the size or age at first reproduction in maturing females, and to count the number of eggs that will be spawned by reproducing females of all ages.

Copulation occurs at night within 2 to 3 min after the mature female molts, during which time sperm are passed into the empty brood pouch by the attending adult male. The eggs are subsequently extruded into the brood pouch where they are fertilized. The eggs hatch from the vitelline membrane after 2 to 3 days. According to Manton (1928) and Nair (1939) a larval ecdysis occurs in the brood pouch shortly before the larvae are liberated. These late stage larvae have movable appendages and pigmented eyes that show through the transparent oostegites of the brooding female. The small quantity of yolk that is present after the larval ecdysis is absorbed, or nearly so, prior to liberation from the brood pouch.

After liberation the larvae tend to sink, then, according to Nair (1939), they undergo a second larval ecdysis after which the statocysts appear and they are capable of swimming. The mysids assume this highly mobile juvenile form within a few minutes after liberation. Although we did not attempt to distinguish sexes of larvae and juveniles, the observations of Nair (1939) indicate that dimorphism is exhibited by the antennules and abdominal appendages even though neither the brood pouch nor the penis is developed.

Incubation time was determined in the laboratory. Adult females and adult males were observed in an aquarium during molting and copulation. Ten females were caught after being observed *in copulo* and were placed in separate containers of sea water at the temperature of their natural environment at that time (17°-19° C). Five of them were removed, at various times, to determine the stages of development of the young. The remaining five all released their young as juveniles on the tenth day after fertilization.

In addition, a large number of nonpregnant adult females were kept in separate containers for various periods up to 157 days. The range of intermolt periods in 218 observations was 5 to 13 days; the median and modal values were both 10 days. There was no obvious temperature effect. The adult females molt just before fertilization and just after liberation of the young; therefore, the average incubation time was taken to be 10 days. This is intermediate between incubation times given for Mysidae that live and reproduce at higher and lower temperatures. Nair (1939) determined the incubation time of *Mesopodopsis orientalis* to be 4 days at 25° to 29° C. Mauchline (1967) reports a minimum incubation time of 3 weeks for *Schistomysis spiritus* at 12.5° C.

MOLTING

To avoid handling and possible injury of the experimental animals, the growth rates were determined by measuring molts. The molts suffered no appreciable decomposition because they were collected on the day following ecdysis. The morphological development of the animals was usually discernable from their molts. But the molts are fragile, split just back of the carapace where the animals emerge, and easily stretched out of shape. Therefore, to measure growth it was necessary to measure a part of the molt that always retained its form and bore a consistent relationship to the body length.

Uropod-Body Length Relationship

The exopod of the uropod (tail fan) was used to estimate the body length of each animal for its previous intermolt period. The uropods were measured from the base (end of last abdominal segment) to the tip, not including spines, which were sometimes broken, with an ocular micro-

meter, at 27.5 × magnification.

The relationship between uropod length and body length was established from a selected series of 94 animals that had been collected in the field and preserved. The series included animals that ranged in body length from 0.8 mm to 7.2 mm, and included late stage larvae, juveniles, immatures, and adults. Both sexes were included; there was no difference between sexes in this relationship.

The body length was measured from the end of the last abdominal segment (base of uropod) to the anterior edge of the carapace, behind the insertion of the eyestalk. Mysids tend to curl when preserved, and they can be distorted to appear longer if they are stretched when measured. To avoid this we chose specimens that were at most only slightly curved, and measured the length of the arc through the midline of those that had significant curvature, rather than the straight line distance between head and tail.

As shown in Figure 1, the relationship between uropod length and body length is linear. The body length is 4.5 times the uropod length.

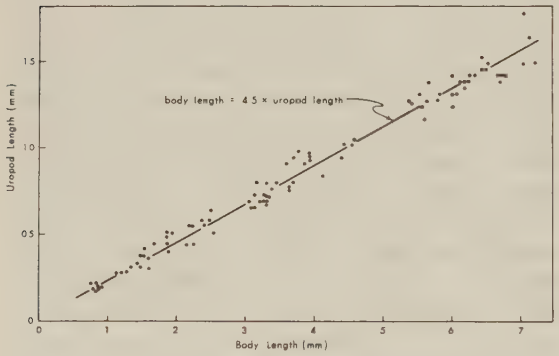


FIGURE 1.—Relationship between uropod length and body length of *Metamysidopsis*.

Molting Frequency

Average intermolt periods were estimated from 414 observations, 146 on males and 268 on females. In many cases several observations were made on the same animal. The maximum period of laboratory survival for a single animal was 157 days, and the maximum number of molts observed for a single animal (not the same animal) was 21. The molting frequency data for animals reared in the laboratory are summarized in Table 1. The sex of the juveniles was established after they had grown large enough to develop obvious morphological differences.

TABLE 1.—Frequency of molting periods observed for *Metamysidopsis* in the laboratory.

Sex and length	Intermolt Period (days)													
	3	4	5	6	7	8	9	10	11	12	13	Mode	Median	Mean
Females														
Body length (mm) 2		8										4	4	4.0
3		6	2									4	4	4.3
4		5	3	1								4	4-5	4.6
5		3	7	7	1	5	2					5-6	6	6.2
6			10	7	9	13	13	28	17	5	8	10	9-10	9.2
7			11	8	6	9	16	12	28	9	9	11	10	9.4
Males														
Body length (mm) 2	11											3	3	3.0
3	2	11	1									4	4	3.9
4	2	15	8	1	1							4	4	4.4
5		6	29	20	4							5	5-6	5.4
6		6	11	8	7	3						5	5-6	5.7

Supplementary data on molting frequency in the field population were obtained indirectly. Over a period of 3 days, 1,211 juveniles + immatures and 2,979 adults were brought into the laboratory late in the day and placed in large aquaria. The following morning all the animals and their molts were collected and counted. Of the juveniles + immatures 218 or 18 % had molted, and of the adults 356 or 12 % had molted. The reciprocal of the relative number molting is an estimate of molting period. The observed reciprocals were 5.6 for juveniles + immatures and 8.3 for adults. Since these values are midway in the ranges shown by laboratory animals (3-8 days for juveniles + immatures and 4-13 days for adults) we assume that the laboratory observations are valid estimates of molting frequency in the population as a whole.

Although our observations were made from February to October, and the water temperatures in the rearing troughs varied from 14° to 20° C, we were unable to detect any obvious effects of temperature or time of year on molting

frequency or growth rates. Nouvel and Nouvel (1939) stated that the intermolt period for *Praunus flexuosis* is least during the warmest months, and the incubatory period is 15 days in August and 3 to 4 weeks in September. Lasker (1966) showed that *Euphausia pacifica* intermolt periods varied as the water temperature fluctuated, and that the intermolt period was shortened by an artificially produced warm period, but that temperatures above 12° C did not accelerate molting further.

Since we do not have evidence to the contrary, we must assume that our laboratory observations on molting frequency provide adequate average values. From the median values given in Table 1 and estimated average growth rates (see below) we have estimated the molting schedules of females and males from juveniles to mature adults as follows:

Females: first six molts — 4 days
seventh molt — 5 days
eighth molt — 6 days
ninth molt — 8 days
tenth molt and thereafter — 10 days

Males: first four molts — 3 days
fifth to eighth molts — 4 days
ninth and tenth molts — 5 days
eleventh molt and thereafter — 6 days

GROWTH AND MATURATION

Evidence of the temporal sequence of growth and maturation can be obtained from following peaks of abundance of size groups in natural populations. We sequentially sampled the mysids in the field and observed some shifting peaks. But we consider that the results are not very reliable because of temporal changes in age-specific mortality rates (Fager and Clutter, 1968). Therefore, all the age-specific growth estimates presented here were obtained from laboratory studies.

Observed Growth

A few mysids were reared in the laboratory from fertilized egg to adult. Several were reared from egg through the juvenile stage. In addition, larger numbers of various sizes were collected in the field and kept in the laboratory for several molts.

The growth data from these animals were combined as shown in Figure 2 (females) and Figure 3 (males). The sexes were separated because the growth and molting rates of males and females are different. As they are shown in Figures 2 and 3, these individual growth curves are simplified and slightly incorrect representations of true growth, for two reasons. First, the growth of the body integument is represented to be continuous, whereas it actually occurs in discrete increments. Second, the age

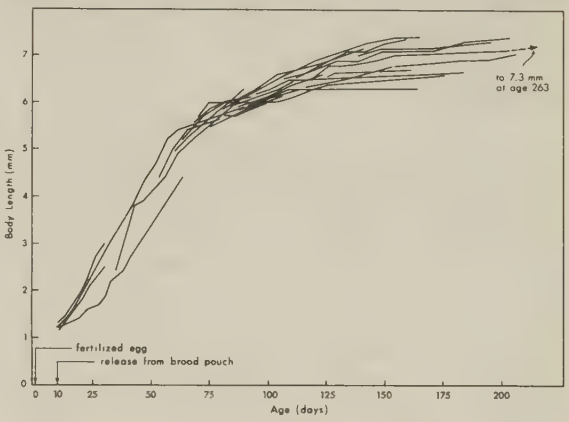


FIGURE 2.—Observed growth in length (from molts) of *Metamysidopsis* females in the laboratory.

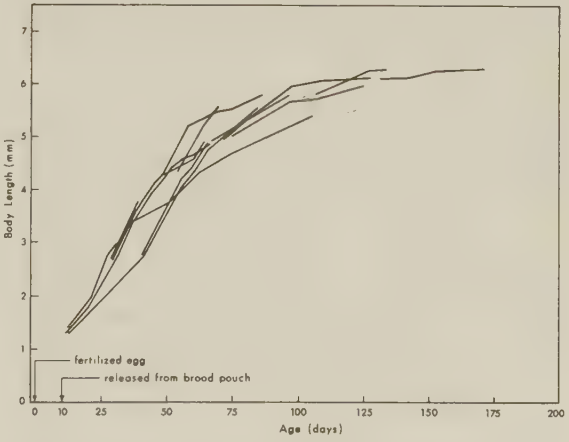


FIGURE 3.—Observed growth in length (from molts) of *Metamysidopsis* males in the laboratory.

shown is the age of the animal at the time it molted, rather than the age at the time that the molted integument was first formed. The procedure for combining the various growth curves of individual animals was to first plot the growth of the animals of known age, and then plot the other growth curves (actual ages unknown) in a manner that showed the least variation from the apparent trend.

Some of the apparent variability in growth rates may be attributable to differences in the temperature at which the growth occurred, but we did not detect any obvious temperature effect. Considerable individual variability occurred among animals of the same size or age that were reared simultaneously.

Maturation

Changes in morphology in relation to size, and known or estimated age, were observed in the molts of animals reared in the laboratory. Observations were made on live females collected from the field population to determine the size at which yolk invested ova first appear in the ovaries. Supplementary observations on the relationship between size and body form were made on preserved animals that had been collected in the field. There is some evidence from previous samples taken for other purposes (Clutter, 1967, 1969) that the relationship between size and stage of development may vary seasonally. But during the period of observations reported here, this did not appear to be significant.

In particular, we wished to determine (1) the size (and subsequently the age) at which males and females were easily distinguishable by their secondary sexual characteristics, (2) the size at the onset of maturity, and (3) the size at which spawning and brooding of eggs and larvae occurs. The external characteristics that most obviously separate males from females of this species are the enlarged oostegites (brood pouches) of the females and the enlarged pleopods (abdominal legs) and antennae of the males.

There is some variability in the size at which the stages of development occur. Therefore, our estimates are average values. The larvae are released and juvenile form is attained at age 10 days; at this time both sexes are about 1.2 mm long (body length; excluding antennae, eyes, and tail fan). Males exhibit sub-adult morphology when about 3.7 mm long, and become mature at 4.3 mm. Females exhibit sub-adult form at 4.0 mm, the ova become infused with yolk at 4.5 mm, and the eggs are extruded into the brood pouch, fertilized, and incubated at slightly less than 5.2 mm.

Average Growth in Length

Average continuous growth curves were fitted by eye to the combined growth data plotted in Figures 2 and 3. These curves are represented by the lower curves (fine, continuous unbroken lines) in Figure 4 (females) and Figure 5 (males). These continuous curves represent the size of the molt at the time—days from fertilization—that the molt was shed. Actually the integument of the animal had attained that size by the beginning of the intermolt period in question. The true growth of the integument of the average animal is represented by the stair-step pattern, which is based on the molting frequency analysis. The broken curved line of continuous growth (Fig. 4 and 5) represents the probable pattern of temporal change in average organic weight of the animal. This curve connects the points halfway between the beginnings and endings of the intermolt periods.

Since the average sizes at various stages of development were determined, it was possible to estimate the average time schedules of maturation and reproduction for females and males on the basis of the growth curves. The average female begins to develop a brood pouch at the seventh molt, 39 days after becoming a fertilized egg. Yolk invested ova begin to be formed at 45 days, during the ninth intermolt period; the ova are extruded into the developed brood pouch and fertilized at the beginning of the tenth intermolt period, at 53 days; and reproduction can occur at 10 day intervals thereafter.

Males and females grow at rates that are indistinguishable up to the age of about 30 days, even though the juvenile males molt more frequently than juvenile females. After that the

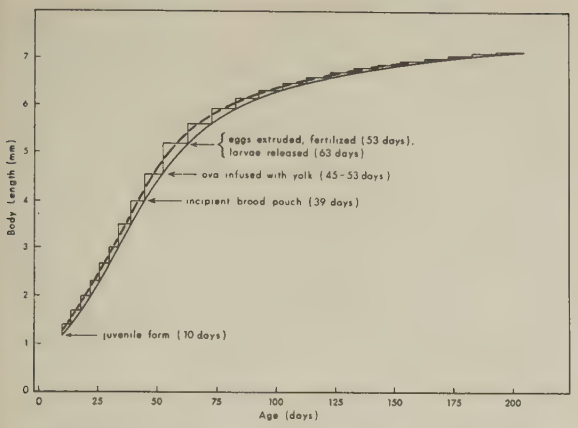

Body Length (mm)
Age (days)
eggs extruded, fertilized (53 days),
larvae released (63 days)
ova infused with yolk (45-53 days)
incipient brood pouch (39 days)
juvenile form (10 days)

FIGURE 4.—Average growth in length of female *Metamysidopsis* in the laboratory. The lower curve (fine continuous line) was fitted to molt size data (Fig. 2). The steps represent changes in integument size. The upper curve (heavy broken line) represents the average size of the animals, assuming that the addition of body tissue is continuous.

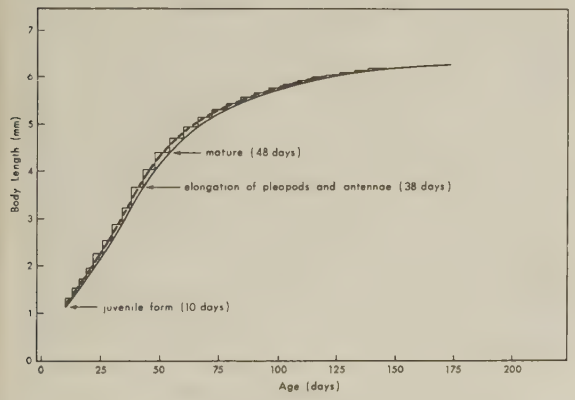


FIGURE 5.—Average growth in length of male *Metamysidopsis* in the laboratory. The lower curve (fine continuous line) was fitted to molt size data (Fig. 3). The steps represent changes in integument size. The upper curve (heavy broken line) represents the average size of the animals, assuming that the addition of body tissue is continuous.

males grow more slowly. The males develop easily recognized secondary sexual characteristics at an average age of 38 days and become sexually mature after about 48 days. Average age at maturity was estimated from observations of testes and copulatory behavior in the laboratory as well as from external morphology.

Average Growth in Weight

To estimate growth in terms of energy it is necessary to translate growth in length into growth in dry weight. This growth in dry weight is then translated into growth in organic (ash-free) weight and thereafter into calories.

The dry weights of *Metamysidopsis* of body lengths ranging from 1.9 mm to 6.5 mm were determined. The animals were captured alive, measured, washed very briefly with distilled water, and dried at 60° C in an oven for 24 hr. They were then weighed individually on a Cahn electrobalance immediately after they were removed from the oven.

The observed relationship between body length and dry weight is shown in Figure 6.

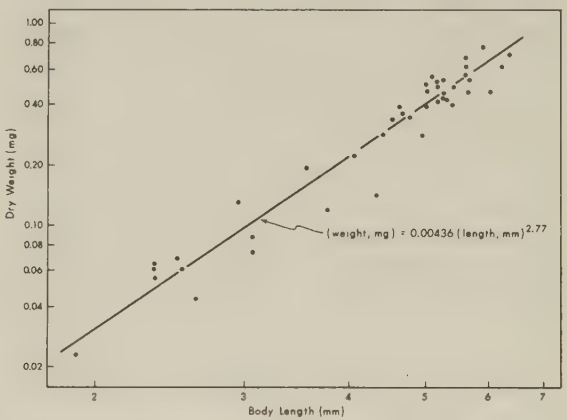


FIGURE 6.—Relationship between body length and dry weight of *Metamysidopsis*.

The equation for the relationship was determined empirically by fitting a straight line to the logarithms of body length and dry weight by the method of Bartlett (1949). The relationship is:

$$\log_e (\text{weight}) = -5.436 + 2.77 \log_e (\text{length})$$

or

$$\text{weight} = 0.00436\ (\text{length})^{2.77}$$

where weight is expressed in mg and length in mm.

It is common to assume that body weight and body volume have a linear relationship, and that body volume is proportional to the third power of length. Therefore dry weight is expected to

be proportional to the third power of body length (Bertalanffy, 1951). The observed relationship does not quite conform to the expected. The relationship between body length and body diameter appears to be linear (Fig. 7); therefore the body volume must be proportional to the third power of the body length. The observed relationship between weight and length could be the result of orthogonal growth of the appendages, which become progressively larger as the animals mature.

From the average length-weight relationship and the average continuous growth in length curves (Fig. 4 and 5) we have calculated the average growth in weight curves shown in Figure 8. The average continuous growth in length curves represented by the heavy broken lines in Figures 4 and 5 were used to calculate growth in weight, because we assume that growth in organic weight is continuous during intermolt periods even though growth of the integument occurs in discrete steps. The estimated growth in weight of males was extrapolated by eye from age 175 days to age 204 days. We do not have laboratory growth estimates for these larger males, but they occurred in the field population.

The average dry weight per egg (140 eggs in sample) was 5.5 μg. Larvae weigh slightly less than this because they lose weight through metabolism while in the brood pouch, even though their ash content is slightly higher than that of the eggs.

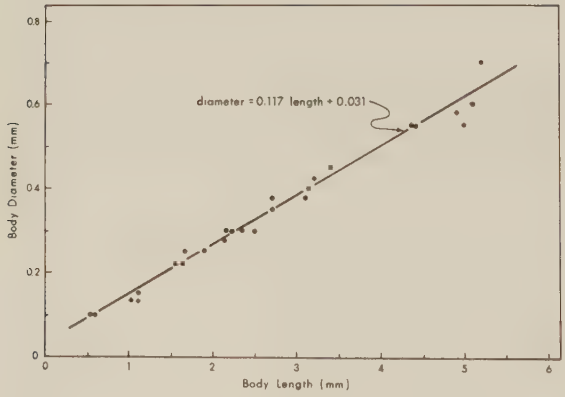


FIGURE 7.—Relationship between body length and body diameter of *Metamysidopsis*.

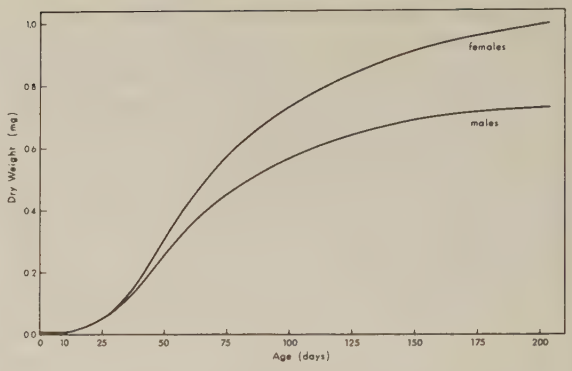


FIGURE 8.—Average growth in dry weight of *Metamydisopsis* females and males in the laboratory.

REPRODUCTION

Data on reproduction and associated energy use are easier to obtain for Mysidae than for most pelagic invertebrates. The eggs and larvae are carried in the brood pouch of the female, and the incipient eggs can be counted prior to their full development and extrusion because the body walls of the mysids are transparent. In addition, copulation and fertilization can be observed in the laboratory, and frequency of pregnancy among mature females can be observed in the natural population through sequential sampling because all stages live in the same area while gestating as they do when not reproducing. Nevertheless, average reproduction rate in these animals is not easy to assess with absolute certainty.

FECUNDITY

Minimum Estimate

The most straightforward way to estimate fecundity is to collect animals in the field, preserve them, and count the number of eggs or larvae carried by females of different sizes. Figure 9 shows the relationship between body lengths and number of young for 310 females collected in the field at various times during the year. The data include 125 females bearing eggs and 185 bearing larvae; we excluded animals that had obviously lost young during capture and preservation. For both eggs and lar-

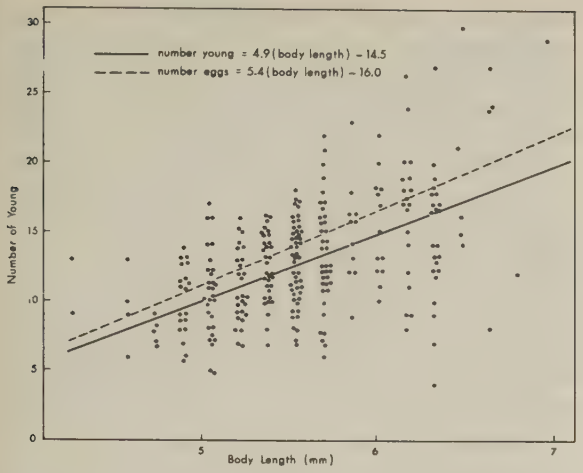


FIGURE 9.—Relationship between body length and number of brood pouch young (eggs and larvae) of preserved animals that were collected in the field. The lower line (continuous) was fitted to the points by the method of Bartlett (1949). The upper line (dashed) represents the equivalent relationship for newly laid eggs, assuming a brood pouch mortality of 0.013/day (see text).

vae, the number of young per female is highly variable. The average relationship between the size of the female and the number of young, calculated by the method of Bartlett (1949), is represented by the straight line: number of young = 4.9 (body length, mm) – 14.5.

This estimate of fecundity is not quite correct because it was made from counts of eggs and larvae that were a few days old. Some eggs and larvae apparently are lost from the brood pouch during the incubation period. Therefore, we adjusted the relationship to account for the mortality which occurs during the incubation period. To estimate the mortality during incubation, counts were made of the maturing ova in the ovaries of 40 adult females and counts were made of late stage larvae in the brood pouches of 27 females of the same size, collected at the same time. The ratio of mean number of larvae/mean number of ova was 0.90. The larvae were estimated to be 8 days old, giving an instantaneous mortality rate of 0.013/day.

The average age of the eggs and larvae from the 310 preserved females (Fig. 9) was estimated to be 7 days. Therefore, the relative survival of the young in the brood pouch between the time of extrusion of the eggs and the estimated average age at which they were counted (7 days) was estimated to be about 0.91. The number of brood pouch young per female was adjusted to the equivalent number of eggs extruded per female by multiplying the number of young by 1/0.91 = 1.10. The relationship (Fig. 9) then becomes: number of eggs = 5.4 (body length, mm) – 16.0, which is shown in Figure 9 as the upper, dashed line.

We consider this to be a minimum estimate of fecundity, because some females that had lost eggs and larvae from the brood pouches during collection and preservation were probably included, despite our attempt to exclude them.

Maximum Estimate

We observed that the females that had released young during the laboratory experiments had a higher apparent fecundity than those that were collected and preserved in the field. It is possible that there was some bias in selecting animals for the laboratory experiments, but we were not aware of any. The number of young released per female is plotted against the body length of the female for those 17 specimens in Figure 10. The average relationship between

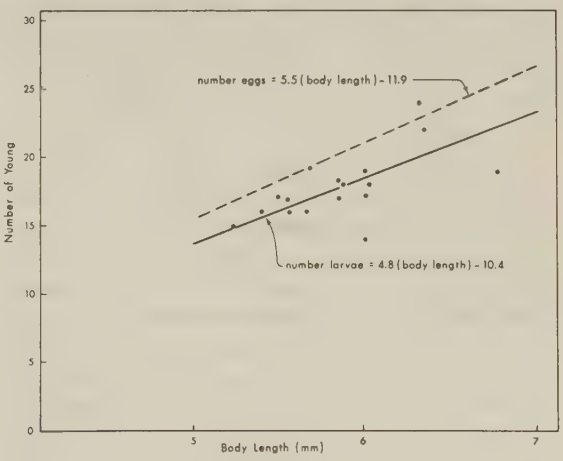


FIGURE 10.—Relationship between body length and number of young released by experimental animals in the laboratory. The lower line (continuous) was fitted to the points by the method of Bartlett (1949). The upper line (dashed) represents the equivalent relationship for newly laid eggs, assuming a brood pouch mortality of 0.013/day (see text).

body length and number of young, calculated by the method of Bartlett (1949), was: number of young = 4.8 (body length, mm) −10.4. This is represented by the lower, unbroken straight line in Figure 10.

This relationship gives estimates of fecundity that are about 1.5 to 2 young per female higher than the relationship calculated from preserved animals. But this is not quite a maximum estimate of fecundity because it does not include the reduction from mortality that occurs during incubation.

As already demonstrated, we can assume a brood pouch mortality rate of 0.013 per day. The relative survival of young in the brood pouch during the 10 days between the extrusion of eggs and the release of larvae was therefore estimated to be 0.87. The number of young released per female was adjusted to the equivalent number of eggs extruded per female by multiplying the number of young by 1/0.87 = 1.15. The relationship (Fig. 10) then becomes: number of eggs = 5.5 (body length, mm) −11.9, which is shown in Figure 10, as the upper, dashed line.

This relationship gives estimates of fecundity that are about four eggs per female higher than the minimum estimates calculated from preserved animals. We consider this to be the maximum estimate of fecundity. It is the same as that used by Fager and Clutter (1968).

COPULATION AND FERTILITY

The fecundity estimates given above apply only to the females that engage in copulation and are fertilized. Mature females that are not fertilized apparently extrude some eggs, but only about one-half the usual number.

Many observations of copulation were made in the laboratory (Clutter, 1969). It occurs in artificial light as well as in the dark, but only at night, between about 2000 and 2400 hr. It occurs within only 2 to 3 min after the mature females molt, and apparently only when the female exudes a pheromone to attract adult males of the same species.

Ten females were captured immediately after they were observed *in copulo* and kept in separate chambers for 10 days. Impregnation had been successful and the usual number of eggs were extruded in every instance. Some adult females that molt do not stimulate males to attend them. Ten adult females were captured after they had been observed to be unattended by males during molting and recovery. They later extruded only about one-half of the normal number of eggs, which eventually disappeared from the brood pouch, presumably because they were infertile. Therefore, the unfertilized females expended only about half the amount of energy in eggs that the fertilized females expended.

Since the mature females are subject to fertilization for only a few minutes following molting, and they apparently do not always attract males during the time, copulation does not always occur. Therefore, not all produce young every 10 days. In a large number of field collections during all seasons, the observed fraction of mature females carrying eggs or larvae in their brood pouches varied from 18 % to 78 %; the mean was 51 %. We are not certain of the source of this variability; there is some evidence that it could be related to population density (Clutter, 1969). We have assumed an average value of 50 % for the purpose of calculating the amount of energy used in reproduction.

On the average, mature females extrude the usual number of eggs about one-half of the time, and they otherwise extrude only one-half of the usual number of eggs. Therefore, the effective average fecundity, in terms of energy used in reproduction (but not in terms of the number of viable young produced), is 0.5 + (0.5) (0.5) = 75 % of the fecundity estimated from counts of young produced/female. For the purpose of calculating the amount of energy used in reproduction the fecundity equations are:

$$\text{minimum — number of eggs} = 4.1\ (\text{body length, mm}) - 12.0$$

$$\text{maximum — number of eggs} = 4.1\ (\text{body length, mm}) - 8.9$$

The second of these relationships is used in the ensuing energy budget calculations.

RESPIRATION

A polarographic oxygen electrode (Kanwisher, 1959) was used in a closed system to measure the respiration rates of *Metamysidopsis*. Both temperature and oxygen were recorded continuously on a strip chart.

The experimental animals were taken from large constant-flow holding tanks (temperature 14°-17° C) and acclimated overnight at the temperature used in the experiments (13.8°-18.1° C), to avoid the overshoot in oxygen consumption described by Grainger (1956). They were then washed in millipore-filtered seawater, counted, and transferred to previously filtered seawater in the oxygen electrode system. In each experiment an attempt was made to use animals of a limited size range. During the run they were held within a 10-ml chamber, baffled at each end with silk screen cloth of 282 μ mesh aperture size. The water in the closed system circulated through this chamber and then past the electrode at a constant rate. The whole system was immersed in a temperature-controlled water bath.

Oxygen use by bacteria was measured by making blank runs with the same water both before and after each test run. Bacterial use amounted to less than 2 %. Oxygen consumption by the mysids was corrected for bacterial uptake. The decrease in relative oxygen tension with time was nearly linear in both the blank runs and the test runs.

The results of the respiration experiments are shown in Table 2. Observed weight-specific

TABLE 2.—Summary of respiration experiments on *Metamysidopsis*.

Specimens	Number	Mean dry weight	Water temperature	Weight-specific respiration rate	
				Uncorrected	Corrected[1]
		Mg.	° *C*	*(µl O₂/mg dry wt hr)*	
Juveniles	99	0.03	13.8	7.71	7.54
Juvenile and immature males and females	176	0.07	18.0	5.40	4.76
"	297	0.08	18.1	5.08	4.48
"	297	0.08	18.1	6.78	5.93
"	132	0.14	13.8	3.92	3.82
Immature females	85	0.28	15.2	1.95	2.46
Males	51	0.31	13.8	3.60	3.53
Brooding females	27	0.47	13.8	3.22	3.16
"	27	0.66	13.8	2.65	2.59

[1] Corrected for oxygen saturation level and corrected to temperature of 16.0° C by using Q_{10} = 1.9 (Grainger, 1956).

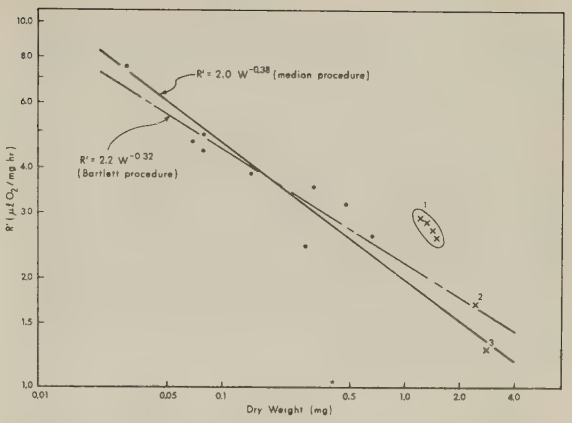


FIGURE 11.—Relation between respiration rate of *Metamysidopsis* and size at 16° C. The symbol R' represents respiration rate per dry unit weight (R/W). The lines were fitted to the circle points by two statistical pocedures. The x points are values calculated from published data on other species of Mysidae: 1-*Neomysis americana* (Raymont and Conover 1961); 2-*Neomysis integer* (Raymont, Austin and Linford 1966); 3-*Hemimysis labornae* (Grainger 1956).

respiration rates (μl O_2/mg dry weight hr) were corrected for the initial percent oxygen saturation and for temperature. In correcting for temperature, a Q_{10} of 1.9 was used (Grainger, 1956). All values were corrected to 16° C, which is about the median of the year-round temperatures that occur in the natural environment of the mysids.

The corrected weight-specific respiration data are plotted in Figure 11 on log-log scales. The symbol R' (Conover, 1960) represents the respiration rate per unit dry weight (R/W). The average relationship between mean dry weight and R' was estimated by two statistical procedures. First, a straight line was fitted to the logarithmically transformed data by the median procedure (Tate and Clelland, 1957). This gave the relationship:

$$R' = 2.0\ W^{-0.38}$$

or

$$R = 2.0\ W^{0.62}$$

where R = respiration rate in μl O_2/hr
and W = mean dry weight in mg.

Second, a straight line was fitted to the logarithmically transformed data by the method of

Bartlett (1949). This gave the relationship:

$$R' = 2.2\ W^{-0.32}$$

or

$$R = 2.2\ W^{0.68}$$

Theoretically, the respiration rate is expected to be proportional to the $^2/_3$ power of weight. Since our estimates are slightly above (0.68) and slightly below (0.62) the expected value of 0.67, we consider that the $^2/_3$ power relationship is the best estimate for *Metamysidopsis* and that the best estimate of respiration rate (μl O_2/hr) is given by the equation:

$$R = 2.1\ W^{0.67}$$

Estimates of weight-specific respiration for three other, somewhat larger, species of Mysidae are compared with *Metamysidopsis* in Figure 11. The upper four points ("1" on Fig. 11) represents results for *Neomysis americana* from Raymont and Conover (1961) that were adjusted from 4° C or 10° C to 16° C by using a Q_{10} value of 1.6 that was estimated from their data. The intermediate point is an estimate of the median value oxygen consumption rate calculated from 12 determinations on *Neomysis integer* (Raymont, Austin, and Linford, 1966) that had been adjusted to 16° C by using a Q_{10} of 1.9 (Grainger, 1956). The lower point was estimated from the results of Grainger (1956) for *Hemimysis lamornae*. The ranges of values for these three larger species are about the same as the range (1-3 μl/hr) calculated from the seasonal change data of Raymont et al. (1966) that had been adjusted to 16° C. The estimates for *Metamysidopsis* and the other three Mysidae all lie well above the relationships calculated for marine planktonic Crustacea by Conover (1960).

BODY COMPOSITION AND ENERGY CONTENT

To estimate the amounts of energy used in respiration, molting, and reproduction it was necessary to determine the body composition of the mysids, their molts, and their young. For these analyses the animals were captured alive and, within 2 hr, placed in a constant-flow holding tank at 15° to 17° C where they were kept for a short time prior to analysis.

BODY COMPOSITION

The estimates of body composition of dried animals and molts are summarized in Table 3. The estimates for ash, protein, lipid, carbohydrate, and chitin are not considered to be accurate past the first decimal point. The fractional percentage values are entered so that the sums will equal 100 %. The methods by which these values were determined will be explained item by item.

To determine dry weights, the animals were washed very briefly with distilled water while still alive, then were oven-dried to constant weight at 60° C. Materials that were available only in small quantities were weighed on a Cahn electrobalance.

Ash

Ash content was estimated by incinerating

TABLE 3.—Average composition and energy content of dry *Metamysidopsis* bodies, molts, eggs, and larvae. Tabulated values for composition are %, and for energy content are cal/mg. The sums of % ash, "protein", lipid, carbohydrate and chitin = 100 %.

	Nitrogen	Carbon	Ash	"Protein"[1]	Lipid	Carbohydrate	Chitin	Energy
	%	%	%	%	%	%	%	*Cal/mg*
Body, whole	11.5	36.8	12.5	69.0	10.0	1.5	7.0	4.60
Body, organic	13.2	42.0	0	79.0	11.4	1.6	8.0	5.24
Molt, whole	--	23.5	44.8	30.9	0	0	24.3	2.48
Molt, organic	--	42.5	0	56.0	0	0	44.0	4.49
Egg, whole	--	58.0	6.0	35.2	58.8	0	0	7.16
Egg, organic	--	61.8	0	37.5	62.5	0	0	7.62
Larva, whole	--	45.7	6.6	60.8	28.9	0	3.7	5.78
Larva, organic	--	48.8	0	65.0	31.0	0	4.0	6.20

[1] "Protein" may include free amino acids.

whole animals or molts in a muffle furnace at 500° C and weighing the residue. Ash determinations were made on six samples composed of mixed animals, juveniles, immatures, adult males, and adult females. The samples contained from 2.7 to 7.3 mg of dried animals; the mean ash content was 12.5 % of the dry weight, and the range was 9.4 to 13.3 %. There was no obvious difference between age groups or sexes. This ash content is within the range, but slightly higher than the mean, of values reported for other Mysidae: *Mysis flexuosa* — 16 % (Hensen, 1887) and 11.9 % (Delff, 1912, quoted by Vinogradov, 1953); *Neomysis integer* — 7.9 % (Raymont, Austin, and Linford, 1964); *Siriella aequiremis* — 10.2 % (Omori, 1969).

Molts used for ash determinations were collected in the laboratory immediately after they were shed. Two samples, weighing 1.1 and 0.6 mg, composed of molts from a wide size range of mysids of both sexes had ash contents of 44.4 % and 45.7 %; the mean was 44.8 %. Lasker (1966) reported a similar value (46 %) for *Euphausia pacifica.* This high ash content in the molts suggests that a large fraction of the total body ash resides in the integuments of the whole animals. From 10 observations, we have found that the dry weight of the molt is on the average 13 % of the dry weight of the animal that sheds the molt. Assuming that the ash content of the molt is the same as the ash content of the integument of the whole animal, we estimate that 47 % of the body ash resides in the integument.

Ash content of brood pouch young was estimated from a large number of specimens taken from live females. A dry sample of 0.6 mg of newly hatched larvae had an ash content of 6.1 %. A sample of 1.2 mg of late stage larvae had an ash content of 6.6 %. Ash content of eggs was not determined; we assume that the ash content is slightly less than that of the newly hatched larvae, and we have used a value of 6.0 %.

Nitrogen and Carbon

Nitrogen content was determined by the micro-Kjeldahl method from three samples of mixed juvenile-adult animals. The dry weights of the samples were 12, 24, and 63 mg, and contained 13.1 %, 11.7%, and 11.2 % nitrogen respectively; the mean was 11.5 % of total dry weight. From a large number of determinations, Raymont et al. (1964) found a value of 11.4 % for *Neomysis integer.* Omori (1969) reported 11.0 % for *Siriella aequiremis,* and Jawed (1969) found 11.9 % for *Neomysis rayii.*

Carbon content was determined with an F and M carbon analyser model 180, described by Lasker (1966). We assume that all organic carbon, including that in chitin, is liberated by this method.

Three samples of females, without young, that weighed 0.2 to 0.4 mg, had carbon fractions between 35.6 % and 38.1 % of dry weight; the mean was 36.8 %. This estimate is intermediate among other values reported for mysids: *Lophogaster* sp. (family Lophogastridae) — 46.8 % (Curl, 1962a); *Neomysis integer* — 30.2 % and 29.5 % (Raymont et al., 1964, 1966); mixed mysids and euphausids — 40.7 % (Beers, 1966); *Siriella aequiremis* — 42.4 (Omori, 1969). From his analysis of several kinds of arthropods, Curl (1962a) found an average of about 38 % of the dry weight as carbon. He points out that this is about ¾ of the commonly assumed value of 50 % (Krogh, 1934).

In our carbon analysis of molts and young, we found that a 0.2-mg sample of fresh dried molts had 23.5 % carbon, a 0.4-mg sample of eggs had 58.0 % carbon, a 0.4-gm sample of midstage larvae had 47.1 % carbon. The carbon contents of the ash-free organic fractions of the material were calculated from these values. Lasker (1966) found 17 % carbon in the molts of *Euphausia pacifica* and 50 % carbon in the eggs.

Macromolecular Components

We assume that the body nitrogen of our species, *Metamysidopsis,* is present as protein, free amino acids, and chitin (Raymont, Austin, and Linford, 1968). We made no evaluation of chitin content, but used the value of 7 % determined for *Neomysis integer* by Raymont et al. (1964). The percent "protein" (may include free amino acids) was estimated by the following relationship, given that 16 % of "protein"

is nitrogen, 6.5% of chitin is nitrogen, and 7 % of the dry body is chitin: 0.16 ("protein") + (0.065) (0.07) = 0.115. From this relationship, the "protein" content of the whole dry body was estimated to be 69 %, which is similar to the value to 71 % protein estimated directly by Raymont et al. (1964) for *Neomysis integer*. According to the estimates of Raymont et al. (1968), the percent nitrogen in proteins of Mysidae may be lower than the value of 16 % commonly assumed for animal tissues. They found 13.3% N in the body protein of *Neomysis integer*, and estimated that about 17 % of what we would have designated as "protein" nitrogen was actually free amino acid nitrogen. They suggest that the amino acids may function in osmoregulation for *Neomysis integer*, which is a euryhaline-brackish water species. We know nothing directly about this for *Metamysidopsis*. Our species lives in a constant oceanic salinity, and we estimated the ash content to be higher than that of *N. integer*. Therefore, a high concentration of free amino acids may not be necessary for osmoregulation in our species. Whatever the ratio of protein/free amino acids may be in *Metamysidopsis*, our energy calculations should not be affected materially.

The lipid content of the mysid bodies was estimated by placing samples of dried, crushed bodies successively for 1 hr in each of two 10-ml portions of ethyl alcohol and two 10-ml washes of petroleum ether. The lipid content was estimated as the difference in dry weight before and after extraction. Two dry samples of mixed animals, weighing 62.9 mg and 13.4 mg, gave values of 9 % and 11 % lipid respectively. A third sample, containing 24.1 mg of brooding females that had full complements of young in their brood pouches, gave a value of 19 % lipid. Linford (1965) found that large females of *Neomysis integer* carrying young had higher lipid contents than males. From our knowledge of the number of young per female and the estimated percent lipid in the young, we calculate that ¼ to ½ of the 19 % lipid value could be contributed by the brood pouch young. Therefore, we have excluded the 19 % value from our estimate, and we have used 10 % as the estimate of average lipid content of the dry bodies. This is slightly less than the value of 13 % estimated for *Neomysis integer* by Raymont et al. (1964), but within the range of means for three species estimated from a large number of determinations by Linford (1965): *Mesopodopsis slavveri* — 9.0 %; *Neomysis integer* — 10.1 %; *Praunus neglectus* — 9.3 %.

The carbohydrate content of the mysids was estimated as the amount of macromolecular material remaining after the average estimates for ash, protein, chitin, and fat are subtracted from the dry weight. This remainder is 1.5 %. Apparently the carbohydrate fraction is low in all pelagic Crustacea. Raymont and Conover (1961) found that 1 % of the dry weight of *Neomysis americana* was glucose; Raymont and Krishnaswamy (1960) found 1.3 % carbohydrate in dry *Neomysis integer;* and Raymont et al. (1964) found 2.4 % carbohydrate in dry *Neomysis integer*.

We did no detailed analyses of the composition of molts, but we assume that the molt is composed of structural materials rather than energy storage materials. Since we consider that carbohydrates and lipids are virtually absent, we entered zero values for them in Table 3. The "protein"/chitin relationship was determined indirectly. First, we estimated the amount of carbon in the average protein of the mysids from the relationship:

$$\begin{aligned}(\%\ \text{C as protein}) = {} & (\%\ \text{C in body}) \\ & - (\%\ \text{C as chitin}) \\ & - (\%\ \text{C as lipid}) \\ & - (\%\ \text{C as carbohydrate}).\end{aligned}$$

The percent carbon in the organic fraction of the body is 42 %, the chitin fraction is taken as 8 %, the chitin is assumed to be 50 % carbon (Curl, 1962a), the lipid content of the organic fraction is 11 %, the lipid is assumed to be 77 % carbon (Lasker and Theilacker, 1962), the carbohydrate fraction is about 2 %, and the carbohydrate is assumed to be 40 % carbon (Curl, 1062a). Therefore, the percent carbon in the

mysid protein is calculated as:

$$\% \text{ C} = \frac{1}{0.79}[0.42 - (0.08)(0.50) - (0.11)(0.77) - (0.02)(0.40)]$$
$$= 0.364$$
$$= 36.4 \%$$

This is considerably less than the average value of 52 % carbon in protein given by Hawk, Oser, and Summerson (1954), but similar to an estimate of 37 % made from the data of Lasker (1966), and higher than an estimate of 23 % made from the data of Raymont et al. (1964).

The second step in finding the relationship between chitin and protein in the molts was to estimate the chitin fraction from the following relationship:

(chitin fraction) (% C in chitin)
+ (protein fraction) (% C in protein)
= (% C in molt)

where

chitin fraction + protein fraction = 1.0.

The chitin fraction calculated from this relationship is 44 % for the organic molt. The protein fraction is therefore estimated to be 56 %. This result suggests that a large fraction of the chitin may be reabsorbed by the animals before molting. This seems reasonable because in Crustacea the new endocuticle is formed during the intermolt period (between 2 % and 46 % of the time between molts, according to Passano, 1960).

To estimate the protein content of eggs and larvae, we have made some arbitrary assumptions that seem reasonable, and that do not measurably affect our energy calculations in any event. We have assumed that the eggs do not contain a measurable amount of carbohydrate, and that they contain little or no chitin because the integument is not yet formed. Therefore, we have assumed that the organic fraction of the eggs is either protein or lipid. For late stage larvae we have also assumed that carbohydrate is absent, but that some chitin is present because they form integument and molt once before they are released. We have assumed that the organic fraction of the larvae contains half the amount of chitin as the adults, or 4 %.

The protein-lipid composition of the eggs was calculated from the carbon content of the ash-free fraction. We have estimated (above) that 36.4 % of the mysid protein is composed of carbon, that 77 % of the lipid is carbon, and that 61.8 % of the ash-free egg is carbon. By using these values we calculate that the organic fraction of the eggs is 62.5 % lipid and 37.5 % protein. The carbon content of intermediate age brood pouch young (about 5 days old) was less than that of eggs and more than that of late stage larvae. For these intermediate age young we calculate a lipid content of 43 %.

ENERGY CONTENT

Juveniles - Adults

The ash-free calorie content of *Metamysidopsis* was determined in a Parr non-adiabatic calorimeter. The data, converted to ash-free values, are given in Table 4. Three of the samples contained so little material that Nujol supplement had to be added to raise the heat of combustion to a measurable level. All three of these measurements fell outside the 95 % confidence limits of the six determinations made without the Nujol supplement. The variability among the three supplemented determinations can be attributed to the ± 2 % variation of the caloric content of the Nujol supplement (10,791 ± 200 cal/g), because the weight of the supplement greatly exceeded the weight of the sample material in each case.

TABLE 4.—Ash-free[1] caloric content of *Metamysidopsis*.

Specimens	Dry weight	Calorie content
	Mg	*Cal/g*
Young juveniles	1.05	[2]3028.9
Juveniles	2.65	[2]6462.6
Young females	4.80	[2]4242.3
Advanced juveniles	12.55	5021.7
Immature males	17.30	5049.0
Immature males	17.30	5358.0
Mature males	15.75	5123.8
Mature females	12.40	5185.7
Mature females	17.25	5699.1

[1] Ash content 12.5 % used in all calculations.
[2] Nujol supplement used in determinations.

The mean for the six nonsupplemented samples is 5,240 cal/g (shown as 5.24 cal/mg in Table 3). No significant differences in energy content among developmental stages nor between sexes were found.

This mean calorie content estimate is somewhat lower than those reported for other crustacea. Slobodkin and Richman (1961) gave values of 5.4 to 5.6 cal/ash-free mg; Lasker (1965) reported a range of 4.9 to 5.4 cal/mg (including ash) for two species of copepods. Our mean value is also lower than the value that can be calculated from the information on body composition, together with reported average values of the calorie content of animal protein, fat, and carbohydrate. Conversion factors given by Morowitz (1968) are: protein, 5.5 cal/mg; fat, 9.3 cal/mg; and carbohydrate, 4.1 cal/mg. Since chitin is glucosamine, we have assumed that it, like carbohydrate, has a calorie content of 4.1 cal/mg. From these conversion factors and the composition data given in Table 3, we calculated an expected value of about 5.77 cal/ash-free mg.

We use the empirical value, 5.24 cal/ash-free mg, in our subsequent energy budget calculations. We consider this to be a conservative estimate, because it assumes that the mysid protein has an energy content of only 4.8 cal/mg. This lower than expected estimate may be related to the empirical observation that the mysid protein contains only 36 % carbon, rather than about 50 % as is commonly assumed for animal protein.

The juvenile and adult *Metamysidopsis* contained 12.5 % ash; therefore, the energy in the whole dry body of an adult or juvenile is estimated to be: (4.6 cal/mg) × (dry weight, mg).

Molts

We estimated the energy content of molts indirectly, because it was difficult to obtain enough material for calorie measurements. The ash-free fraction (55 %) of the molts was estimated to be composed of 44 % chitin and 56 % protein. By assuming that chitin has an energy content of 4.1 cal/mg, and that the mysid protein has an energy content of 4.8 cal/mg, we calculate that the ash-free fraction of the molts has an energy content of 4.5 cal/mg.

From a sample of 10 animals and their molts we found that the dry weight of molts is on the average 13 % (range 9-19%) of the dry weight of the animals that shed them. Lasker (1964, 1966) and Jerde and Lasker (1966) found that the dry molts of a euphausiid were about 10 % of the dry weight of the animals that produced them (range 4-14 %).

The energy lost by molting *Metamysidopsis* is therefore proportional to the size of the animal:

$$(0.13)\,(0.55)\,(4.5\ \text{cal/mg}) \times (\text{dry weight of animal, mg})$$

or

$$(0.32\ \text{cal/mg}) \times (\text{dry weight of animal, mg}).$$

Eggs and Larvae

We estimated that eggs were 6 % ash, 35 % protein, and 59 % lipid. The energy content of an egg is estimated to be: (0.35) (4.8 cal/mg) + (0.59) (9.3 cal/mg) = 7.16 cal/mg. A sample of 140 eggs was dried and weighed; the mean dry weight per egg was 0.0055 mg. The energy content per egg is therefore 0.039 calorie.

We estimated that, just before being released from the brood pouch, the larvae are about 6 % ash, 61 % protein, 29 % lipid, and 4 % chitin. The energy content of a late stage larva is estimated to be: (0.61) (4.8 cal/mg) + (0.29) (9.3 cal/mg) + (0.04) (4.1 cal/mg) = 5.78 cal/mg. The mean dry weight per larva, estimated from 110 individuals, was 0.0051 mg. The energy content per larva is therefore 0.029 calorie.

ENERGY BUDGET AND EFFICIENCY OF ENERGY TRANSFER

From the data on average growth, age-specific fecundity, respiration rate, and energy content we have calculated cumulative curves of energy use by individual mysids in attaining various stages of development. Data on age-specific natural mortality rates (Fager and Clutter 1968) were used to estimate l_x (probability

of animal being alive at age x) schedules and average generation time of the field population. The field and laboratory data were combined in an analysis of the efficiency of energy transfer through the *Metamysidopsis* population to the organisms that feed on them.

CUMULATIVE ENERGY CURVES

At age zero the egg contains about 0.04 cal. Ten days later, at the time it is released from the brood pouch, the larva contains about 0.03 cal. Thereafter the average calorie content increases in proportion to the dry weight (4.6 cal/mg). The average schedules of energy incorporation differ between males and females after about 30 days; the rate of incorporation becomes lower and levels off sooner in males. The accumulation of body energy is shown as the lowest curves in Figure 12 (females) and Figure 13 (males).

The amount of energy lost in molts varies with age because the size of the molt increases and the molting frequency decreases. Females and males have different cumulative losses of energy from molting because their growth rates are different after age 30 days, and their molting frequencies are different (Table 1.) Although the actual loss of energy in molting occurs at discrete intervals, we have plotted the cumulative energy loss as smooth curves, because the accumulation of energy for integument formation probably is continuous. Cumulative energy loss in molting is shown as the second curve in Figure 12 (females) and Figure 13 (males). The cumulative energy curves are additive, i.e. the area between the first curve (body energy) and second curve (molting energy) represents the cumulative energy loss in molts.

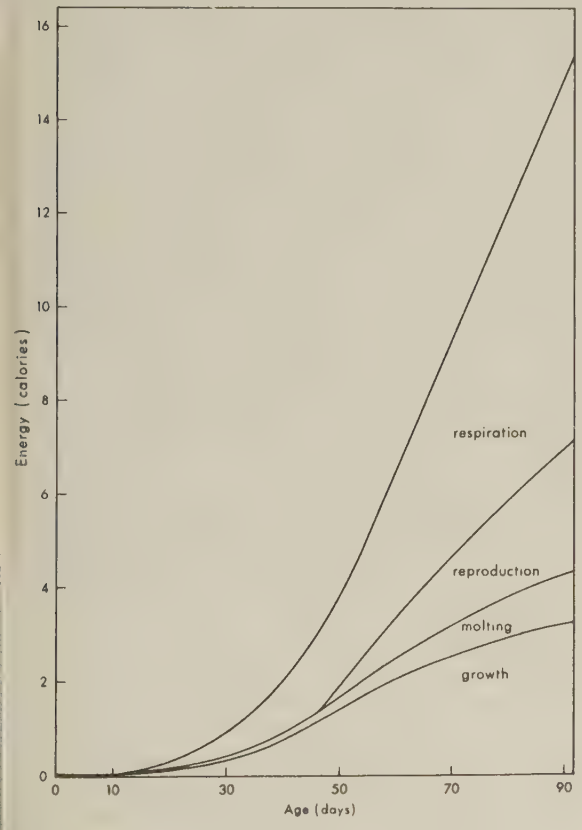


FIGURE 12.—Cumulative energy used by individual *Metamysidopsis* females. The curves are additive, i.e. the space between the lower two curves represents the cumulative energy lost in molts, the next higher space represents energy used to produce eggs (both fertilized and unfertilized), etc.—so that the upper curve represents cumulative energy used for all processes.

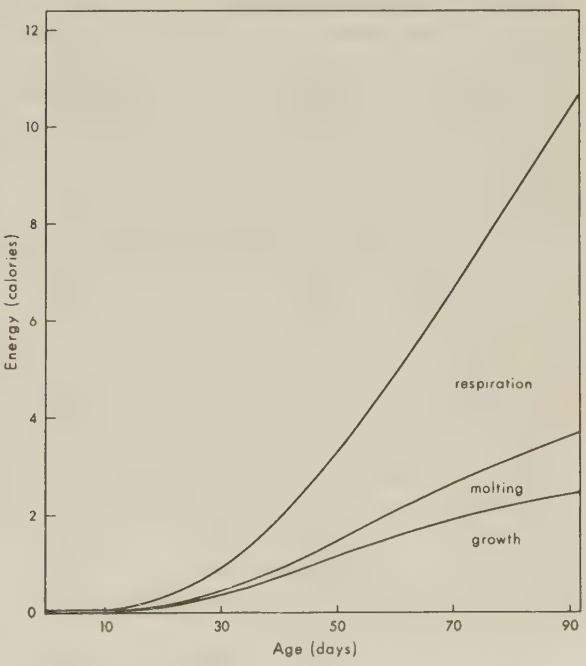


FIGURE 13.—Cumulative energy used by individual *Metamysidopsis* males. The curves are additive (see Fig. 12).

Males use a small amount of energy in producing sperm, but we assume that this is negligible. In females, the ova begin to be infused with yolk about age 45 days. The actual discharge of eggs occurs at discrete intervals of about 10 days, beginning at age 53 days. We assume that the accumulation of energy for reproduction is more continuous than this, therefore we have shown reproductive energy use as a smooth curve. The reproduction energy curve shown in Figure 12 is based on the maximum fecundity estimate given previously [number of eggs = 4.1 (body length, mm) — 8.9]. A reproduction energy curve based on our minimum estimate of fecundity [number of eggs = 4.1 (body length, mm) — 12.0] would be 0.12 cal (3.1 eggs) lower per spawning. This would make the minimum estimate 72 % of the maximum estimate at the age of first spawning (53 days) and progressively higher in percentage thereafter, e.g. 85 % at the age of fifth spawning (93 days). All our reproduction energy calculations take into account the observation that, on the average, mature females extrude the usual number of eggs only one-half of the time and otherwise extrude only one-half the usual number of eggs.

The amount of energy used in respiration was calculated from the weight-specific respiration equation: $R' = 2.1$ (dry weight, mg) $^{-0.33}$, and from energy conversion factors based on our estimates of body composition.

We do not know what substrate *Metamysidopsis* catabolizes. The organic fraction of the body is largely protein; the storage product (carbohydrate and lipid) content is low. Raymont and Krishnaswamy (1960) observed that the carbohydrate content of *Neomysis integer* decreased slightly, from about 1.30 % (of dry weight) to 1.06 %, when a marked reduction in feeding occurred. For the same species, Linford (1965) found no significant change in lipid level whether the animals were starved, fed a lipid-free diet, or fed a high lipid diet. Raymont et al. (1968) asserted that *N. integer* uses protein as an energy source.

We agree with Linford (1965) that it seems likely that the mysids must live largely on their daily ingestion. We think that the food they ingest has composition similar to their bodies. Therefore, our energy calculations assume that they use catabolic substrates in proportion to their presence in the body. This is supported by the results of Jawed (1969). To convert the amount of oxygen used in respiration into the equivalent energy lost as heat we have used the following values for calories lost/μl O_2 consumed (Hawk et al., 1954; Prosser, 1950): protein, 4.5×10^{-3}; lipid, 4.7×10^{-3}; carbohydrate, 5.0×10^{-3}. Therefore, our estimate of the average amount of energy used in respiration is about 4.5×10^{-3}cal μl O_2.

The cumulative energy used in respiration is shown as the uppermost curve in Figure 12 (females) and Figure 13 (males). The area between that curve and the next lower curve represents the catabolic heat loss. These respiration data were calculated for a temperature of 16° C, which was the median temperature of the natural environment of *Metamysidopsis*. Our respiration measurements were made in flowing water during the daylight hours. Therefore, they represent basal metabolism + energy expended in active swimming. There is some evidence (Clutter, 1969) that the mysids may be less active at night, even though they continue to swim at all times. For this reason we think that the field population may use somewhat less than this amount of energy in respiration.

Our estimated rate of energy loss in catabolism is higher than that estimated by Jawed (1969) in his study of nitrogen excretion in *Neomysis rayii*. He suggested that protein is catabolized in relatively large quantities, therefore nitrogenous excretion may provide a good estimate of catabolism. He found an average catabolism of about 2.5 % of body nitrogen per day in adult animals that were probably 8 to 10 mg dry weight, that were held at 10° C. The rate for adult *Metamysidopsis* of average size (0.6-0.8 mg) was 5 to 6 % of the body energy per day. This disparity in catabolism may result from differences between the size and between the environmental temperatures of the two species.

Jawed (1969) showed that about 15 % of the nitrogen was excreted as amino acids. We did

not investigate this in *Metamysidopsis*, therefore, our estimate of total catabolism could be slightly low because it includes only losses of heat energy.

NET ECOLOGICAL EFFICIENCY

Mortality and Generation Time

Estimates of natural mortality in the field population were made during the same period that the laboratory growth experiments were done (Fager and Clutter, 1968).

Brood pouch mortality rate was estimated to be 0.013/day (maximum of 0.017/day). Mortality rates for juveniles, immatures, and adults were estimated from consecutive series of field collections. The field mortality rates varied during the year. Survival curves (l_x = probability of being alive at age x) for periods of at least mortality, median mortality, and greatest mortality are shown in Figure 14. The mortality rates that we used to calculate these l_x curves are shown in Table 5. The greatest mortality rate results in a declining population; at the median mortality rate the population size remains about constant; and at the least mortality rate the population increases.

An average female first reproduces at about age 53 days. The generation length for the population is somewhat longer because the females reproduce more than once. The generation length for the field population varied between 67 days and 71 days; the median was 68 days (Fager and Clutter, 1968).

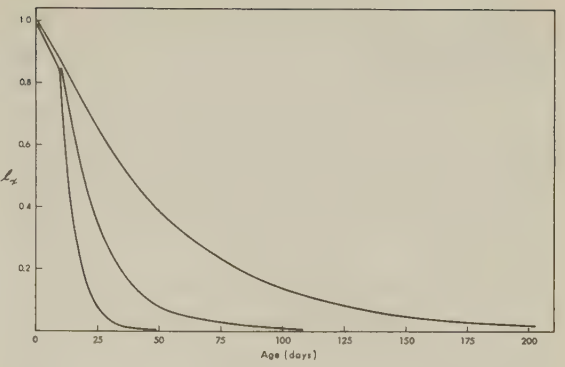


FIGURE 14.—Age specific survival (l_x = probability of being alive at age x) of *Metamysidopsis* calculated from estimates of greatest, median, and least mortality in the field population (Table 5).

TABLE 5.—Mortality rates (per day) used to calculate l_x schedules for the *Metamysidopsis* field population.

Specimens	Least mortality	Median mortality	Greatest mortality
Brood pouch young	0.013	0.013	0.017
Juveniles	0.02	0.06	0.15
Immatures	0.02	0.05	0.14
Adults	0.02	0.04	0.13

Relative Energy Use by Individuals

We determined the calories of energy used by average individual female and male mysids, and the fractions used for growth, molting, reproduction, and respiration from the estimates of cumulative energy use (shown in part in Figures 12 and 13). The amounts and the percentage distributions required to reach selected stages of development are shown in Table 6.

TABLE 6.—Energy used by individual *Metamysidopsis* to reach selected stages of development.

	Age	Energy	Relative use			
			Respiration	Reproduction	Molting	Growth
	Days	*Cal*	%	%	%	%
Females:						
Egg yolk production	45	2.7	52	0	8	40
First reproduction	53	4.6	49	9	7	35
Generation	68	8.7	50	15	7	28
l_x = 0.01	[1]103	18.4	55	19	7	19
Males:						
Maturity	48	3.0	54	0	10	36
l_x = 0.01	[1]103	12.8	67	0	12	21

[1] Approximate age at which l_x = 0.01 in a nearly stable population ($r \sim 0$).

The indicated age at which the probability of being alive reaches 0.01 applies to the stable population (median death rates).

The males require less energy to reach maturity than females, but relatively more of this energy goes into molting and respiration and less is incorporated. Two-thirds of the energy used in reproduction remains in the population; one-third is lost as unfertilized eggs.

The estimates of relative use of assimilated food by *Metamysidopsis* females during a life span are compared with estimates for a copepod and a euphausid (Corner, Cowey, and Marshall, 1967) in Table 7. The mysids apparently use a fraction of assimiliated energy for growth that is intermediate between the other two species, a lower fraction for metabolism, and a higher fraction for producing eggs.

TABLE 7.—Use of assimilated food by *Metamysidopsis* females (life span 103 days) compared with the copepod *Calanus finmarchicus*[1] (life span 10 weeks) and the euphausid *Euphausia pacifica*[2] (life span 20 months).

	Assimilated energy used by *Metamysidopsis*	Assimilated N used by *Calanus*	Assimilated C used by *Euphausia*
	%	%	%
Growth	19	25.3	10.1
Metabolism	55	61.4	72.3
Molts	7	0.9	16.6
Eggs	19	12.4	1.0

[1] From Corner, Cowey, and Marshall (1967).
[2] From Lasker (1966), revised in Corner et al.

Relative Energy Use by the Population

The values of relative energy use given in Tables 6 and 7 apply to individuals, or to populations wherein all members live a full life span. They do not apply to the natural population, because some die during all stages of growth.

We have estimated the relative amounts of energy that would be lost by populations in respiration, production of infertile eggs, molting, and mortality at the observed minimum, median and maximum mortality rates shown in Table 5. This was done by calculating the fraction of the population that died during each intermolt period ($\triangle l_x$), and multiplying this times: (1) the mean body energy content for the midpoint of that period, (2) the quantity of cumulative energy lost in infertile eggs up to the midpoint of that period, and (4) the quantity of cumulative energy used in respiration up to the midpoint of that period. The product values for each of these loss categories (mortality, molting, etc.) were then summed over all ages (to $l_x \sim 0.001$). The relative energy use values were calculated as fractions of the overall sum for all categories combined. We excluded fertilized eggs because this reproduction energy is retained in the population.

The age specific distribution of energy use (representing energy loss, because fertilized eggs are excluded) by a population (females and males) of *Metamysidopsis* at the median mortality rate is illustrated in Figure 15. All the curves are plotted with reference to the base line, zero. The rate of energy loss is low among eggs and larvae, and much higher among the juveniles that have just emerged from the brood pouch and begun to swim. In the larger animals, the respiration per unit weight is lower, but the respiration per animal is higher, so that the respiration rate per day is highest among the animals that are about 25 days old. The loss of energy per day from all causes is highest among the animals that are about 30 days old. After this the curve declines because the effect of larger size becomes less than the effect of smaller numbers.

The estimated relative amounts of energy lost by the population of females, males, and both sexes combined, for each loss category and

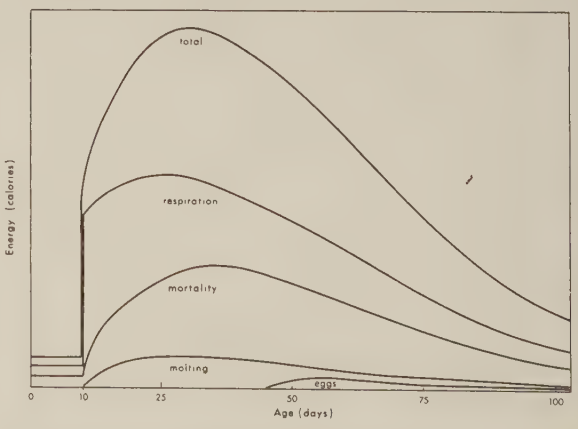


FIGURE 15.—Age specific distribution of energy loss by a *Metamysidopsis* population at the median mortality rate. Production of fertilized eggs is excluded.

for each of three mortality rates, are shown in Table 8. The percentages for females and males combined are not quite the same as the means of the separate percentages for females and for males. At the minimum death rate 55 % of the energy loss would pass through the female half of the population (58 % if fertile eggs are included). At the median death rate 52 % would pass through the females, and at the maximum death rate, 50 %.

TABLE 8.—Relative amount (%) of energy lost by *Metamysidopsis* populations in respiration, production of infertile eggs, molting, and mortality; at minimum, median and maximum mortality rates.

Sex	Death rate	Respiration	Infertile eggs	Molting	Mortality
		%	%	%	%
Females	minimum	63.7	6.7	8.6	20.9
	median	55.6	3.7	7.7	33.0
	maximum	45.4	0.1	6.1	48.4
Males	minimum	67.4	0.0	12.6	20.0
	median	58.3	0.0	9.9	31.8
	maximum	47.9	0.0	6.5	45.6
Females and Males	minimum	64.5	3.7	10.4	20.5
	median	56.9	1.9	8.8	32.4
	maximum	46.7	0.1	6.3	47.0

If we assume that all the mortality is yield to predators (Odum and Smalley, 1959; Engelmann, 1961), our mortality fractions are an estimate of net ecological efficiency (energy yield/energy assimilated). Apparently some Crustacea regularly die from natural causes other than mortality (e.g. *Daphnia,* Slobodkin, 1959). Many mysids of all ages died in our laboratory cultures, but we do not attribute this to senescence. In the field and in the laboratory we observed *Metamysidopsis* much older than the oldest animals that are involved significantly in our energy calculations. Our best estimate of the net ecological efficiency of the mysid population, for transfer of energy to a higher trophic level, such as fishes, is about 32 %. The net efficiency of transfer to all trophic levels is 1 — respiration fraction = 43 %.

ASSIMILATION AND GROSS ECOLOGICAL EFFICIENCY

Assimilation Efficiency

Gross ecological efficiency (energy yield/energy ingested) is the product of net ecological efficiency (energy yield/energy assimilated) × assimilation efficiency (energy assimilated/energy ingested). Therefore, an estimate of assimilation efficiency is required to estimate gross ecological efficiency for the mysid population.

We attempted to estimate the assimilation efficiency of *Metamysidopsis* directly by a carbon-14 method described by Lasker (1960). This failed because the mysids did not filter sufficient amounts of radioactive phytoplankton. An experiment with another member of the family Mysidae, taken from the same area, was successful. This gave an estimate of 90 % assimilation efficiency.

Lasker (1966) obtained a similar high value (84 %) for the morphologically similar *Euphausia pacifica;* and Marshall and Orr (1955) found values greater than 90 % for the copepod *Calanus finmarchicus.* In his detailed reviews of assimilation in zooplankton, Conover (1964, 1966) suggests that these values probably are too high. The very large number of observations, many of them his own, that are cited by Conover seem to be evidence that, although variable, the mean assimilation efficiency for crustacean zooplankton is at least 60 % and perhaps greater.

Gross Ecological Efficiency

From the information presently available we consider that the assimilation efficiency of the mysids is between 60 % and 90 %. Our best estimate of net ecological efficiency (yield/assimilated) is 32 %. Therefore, the minimum estimate of gross ecological efficiency (yield/ingested) is 19 % and the maximum estimate is 29 %.

These estimates are well within the broad range of available estimates of gross ecological efficiency (see reviews by Patten, 1959; Slobodkin, 1961; Phillipson, 1966; Reeve, 1966), and within the range of 8 % to 30 % that Engelmann (1961) considers to be acceptable. They are about 2 to 3 times as high as the median value of 10 % that is suggested by Slobodkin (1961, 1962), but lower than the values of 30 % to 50 % suggested for marine zooplankton by

Ketchum (1962), Steemann Nielsen (1962), and Curl (1962b).

LITERATURE CITED

BARTLETT, M. S.
1949. Fitting a straight line when both variables are subject to error. Biometrics 5(3), 207-212.

BEERS, JOHN R.
1966. Studies on the chemical composition of the major zooplankton groups in the Sargasso Sea off Bermuda. Limnol. Oceanogr. 11(4): 520-528.

BERTALANFFY, LUDWIG VON.
1951. Metabolic types and growth types. Amer. Natur. 85(821): 111-117.

BLEGVAD, H.
1922. On the biology of some Danish gammarids and mysids. (*Gammarus locusta, Mysis flexuosa, Mysis neglecta, Mysis inermis*). Rep. Dan. Biol. Sta. 28, 103 p.

CLUTTER, ROBERT I.
1965. Self-closing device for sampling plankton near the sea bottom. Limnol. Oceanogr. 10(2): 293-296.
1967. Zonation of nearshore mysids. Ecology 48(2): 200-208.
1969. The microdistribution and social behavior of some pelagic mysid shrimps. J. Exp. Mar. Ecol. 3(2): 125-155.

CONOVER, ROBERT J.
1960. The feeding behavior and respiration of some marine planktonic Crustacea. Biol. Bull. 119(3): 399-415.
1964. Food relations and nutrition of zooplankton. *In* Experimental marine ecology, p. 81-91. Grad. Sch. Oceanogr. Univ. R.I., Occas. Publ. 2.
1966. Assimilation of organic matter by zooplankton. Limnol. Oceanogr. 11(3): 338-345.

CORNER, E. D. S., C. B. COWEY, AND S. M. MARSHALL.
1967. On the nutrition and metabolism of zooplankton. V. Feeding efficiency of *Calanus finmarchicus*. J. Mar. Biol. Ass. U. K. 47(2): 259-270.

CURL, HERBERT, JR.
1962a. Analyses of carbon in marine plankton organisms. J. Mar. Res. 20(3): 181-188.
1962b. Standing crops of carbon, nitrogen and phosphorus and transfer between trophic levels, in continental shelf waters south of New York. Rapp. Proces-Verbaux Reunions, Cons. Perma. Int. Explor. Mer. 153: 183-189.

ENGELMANN, MANFRED D.
1961. The role of soil arthropods in the energetics of an old field community. Ecol. Monogr. 31(3): 221-238.

FAGER, E. W., AND R. I. CLUTTER.
1968. Parameters of a natural population of a hypopelagic marine mysid, *Metamysidopsis elongata* (Holmes). Physiol. Zool. 41(3): 257-267.

FAGER, E. W., A. O. FLECHSIG, R. F. FORD, R. I. CLUTTER, AND R. J. GHELARDI.
1966. Equipment for use in ecological studies using SCUBA. Limnol. Oceanogr. 11(4): 503-509.

GRAINGER, J. N. R.
1956. Effects of changes of temperature on the respiration of certain Crustacea. Nature (London) 178(4539): 930-931.

HAWK, PHILIP B., BERNARD L. OSER, AND WILLIAM H. SUMMERSON.
1954. Practical physiological chemistry. 13th ed. McGraw-Hill, New York. xvi + 1439 p.

HENSEN, V.
1887. Über die Bestimmung des Plankton's oder des im Meere treibenden Materials an Pflanzen und Thieren. Ber. Komm. Wiss. Unters. Deuts. Meere, Kiel. 5: 1-107.

JAWED, MOHAMMAD.
1969. Body nitrogen and nitrogenous excretion in *Neomysis rayii* Murdoch and *Euphausia pacifica* Hansen. Limnol. Oceanogr. 14(5): 748-754.

JERDE, CHARLES W., AND REUBEN LASKER.
1966. Molting of euphausiid shrimps: Shipboard observations. Limnol. Oceanogr. 11(1): 120-124.

KANWISHER, JOHN.
1959. Polarographic oxygen electrode. Limnol. Oceanogr. 4(2): 210-217.

KETCHUM, BOSTWICK H.
1962. Regeneration of nutrients by zooplankton. Rapp. Proces-Verbaux Reunions, Cons. Perma. Int. Explor. Mer 153: 142-147.

KREBS, H. A., AND H. L. KORNBERG.
1957. Energy transformations in living matter, a survey. Springer, Berlin. p. 212-298.

KROGH, AUGUST.
1934. Conditions of life at great depths in the ocean. Ecol. Monogr. 4(4): 430-439.

KURATA, HIROSHI.
1960. Increase in size at moulting in Crustacea. Bull. Hokkaido Reg. Fish. Res. Lab. 22: 148. [In Japanese with English summary.]

LASKER, REUBEN.
1960. Utilization of organic carbon by a marine crustacean: Analysis with carbon-14. Science 131(3407): 1098-1100.
1964. Moulting frequency of a deep-sea crustacean, *Euphausia pacifica*. Nature (London) 203 (4940): 96.
1965. The physiology of Pacific sardine embryos and larvae. Calif. Coop. Oceanic Fish. Invest. Rep. 10: 96-101.
1966. Feeding, growth, respiration, and carbon utilization of a euphausiid crustacean. J. Fish. Res. Bd. Can. 23(9): 1291-1317.

LASKER, REUBEN, AND GAIL H. THEILACKER.
1962. The fatty acid composition of the lipids of some Pacific sardine tissues in relation to ovarian maturation and diet. J. Lipid Res. 3(1): 60-64.
1965. Maintenance of euphausiid shrimps in the

laboratory. Limnol. Oceanogr. 10(2): 287-288.

LINFORD, EILEEN.
1965. Biochemical studies on marine zooplankton. II. Variations in the lipid content of some Mysidacea. J. Cons. Cons. Perma. Int. Explor. Mer 30(1): 16-27.

MANTON, S. M.
1928. On the embryology of a mysid crustacean, *Hemimysis lamornae*. Phil. Trans. Roy. Soc. London, Ser. B 216: 363-463.

MARSHALL, S. M., AND A. P. ORR.
1955. On the biology of *Calanus finmarchicus*. VIII. Food uptake, assimilation and excretion in adult and stage V *Calanus*. J. Mar. Biol. Ass. U.K. 34(3): 495-529.

MAUCHLINE, J.
1967. The biology of *Schistomysis spiritus* [Crustacea, Mysidacea]. J. Mar. Biol. Ass. U.K. 47(2): 383-396.

MOROWITZ, HAROLD J.
1968. Energy flow in biology. Academic Press, New York. ix + 179 p.

NAIR, K. BHASKARAN.
1939. The reproduction, oogenesis and development of *Mesopodopsis orientalis* Tatt. Proc. Indian Acad. Sci., Sect. B 9(4): 175-223.

NOUVEL, HENRI, AND LOUISE NOUVEL.
1939. Observations sur la biologie d'une Mysis: *Praunus flexuosus* (Müller, 1788). Bull. Inst. Oceanogr. Monaco 761, 10 p.

ODUM, EUGENE P., AND ALFRED E. SMALLEY.
1959. Comparison of population energy flow of a herbivorous and a deposit-feeding invertebrate in a salt marsh ecosystem. Proc. Nat. Acad. Sci. U.S.A. 45(4): 617-622.

OMORI, MAKOTO.
1969. Weight and chemical composition of some important oceanic zooplankton in the North Pacific Ocean. Mar. Biol. 3(1): 4-10.

PASSANO, L. M.
1960. Moulting and its control. *In* Talbot H. Waterman (editor), The physiology of Crustacea. Vol. 1, p. 473-536. Academic Press, New York.

PATTEN, BERNARD C.
1959. An introduction to the cybernetics of the ecosystem: The trophic-dynamic aspect. Ecology 40(2): 221-231.

PHILLIPSON, JOHN.
1966. Ecological energetics. St. Martin's Press, New York. 57 p.

PROSSER, C. LADD (editor).
1950. Comparative animal physiology. W. B. Saunders Company, Philadelphia. ix + 888 p.

RAYMONT, J. E. G., J. AUSTIN, AND EILEEN LINFORD.
1964. Biochemical studies on marine zooplankton. I. The biochemical composition of *Neomysis integer*. J. Cons. Cons. Perma. Int. Explor. Mer 28(3): 354-363.
1966. Biochemical studies on marine zooplankton. III. Seasonal variation in the biochemical composition of *Neomysis integer*. *In* Harold Barnes (editor), Some contemporary studies in marine science, p. 597-605. George Allen and Unwin Ltd., London.
1968. Biochemical studies on marine zooplankton. V. The composition of the major biochemical fractions in *Neomysis integer*. J. Mar. Biol. Ass. U.K. 48(3): 735-760.

RAYMONT, J. E. G., AND ROBERT J. CONOVER.
1961. Further investigations on the carbohydrate content of marine zooplankton. Limnol. Oceanogr. 6(2): 154-164.

RAYMONT, J. E. G., AND S. KRISHNASWAMY.
1960. Carbohydrates in some marine planktonic animals. J. Mar. Biol. Ass. U.K. 39(2): 239-248.

REEVE, M. R.
1966. Observations on the biology of a chaetognath. *In* Harold Barnes (editor), Some contemporary studies in marine science, p. 613-630. George Allen and Unwin Ltd., London.

SLOBODKIN, L. BASIL.
1959. Energetics in *Daphnia pulex* populations. Ecology 40(2): 232-243.
1961. Growth and regulation of animal populations. Holt, Rinehart and Winston, New York. viii + 184 p.
1962. Energy in animal ecology. *In* J. B. Cragg (editor), Advances in ecological research. Vol. 1, p. 69-101. Academic Press, London.

SLOBODKIN, L. B., AND S. RICHMAN.
1961. Calories/gm. in species of animals. Nature (London) 191(4785): 299.

STEEMANN NIELSEN, E.
1962. The relationship between phytoplankton and zooplankton in the sea. Rapp. Proces-Verbaux Reunions, Cons. Perma. Int. Explor. Mer 153: 178-182.

TATE, MERLE W., AND RICHARD C. CLELLAND.
1957. Nonparametric and shortcut statistics. Interstate Publishers and Printers, Inc., Danville, Ill. ix + 171 p.

VINOGRADOV, A. P.
1953. The elementary chemical composition of marine organisms. Mem. Sears Found. Mar. Res. 2, xiv + 647 p.

A LINEAR-PROGRAMMING SOLUTION TO SALMON MANAGEMENT[1]

BRIAN J. ROTHSCHILD[2] AND JAMES W. BALSIGER[3]

ABSTRACT

A linear-programming model was constructed to allocate the catch of salmon among the days of the salmon run. The objective of the model was to derive a management schedule for catching the salmon which would result in maximizing the value of the landings given certain constraints. These constraints ensured that cannery capacity was not exceeded, and that escapement of both male and female fish was "adequate." In addition to considering the allocation of the catch in the primal problem, the dual problem considered the shadow prices or marginal value of the various sizes of fish, eggs, and cannery capacity, thus enabling the manager to view his decisions in light of the marginal values of these entities. As an example, the model was applied to a run of sockeye salmon in the Bristol Bay system. In the particular example, which was chosen to replicate the 1960 run, the additional value of the catch owing to optimality amounted to an ex-vessel value of a few hundred thousand dollars. In addition it appeared that the required processing time could be reduced by several days. The optimum allocation was obtained through conformance to the linear-programming model. The cost of this conformance was not, however, determined.

The Pacific salmon fisheries have been cited as an example of irrational conservation (Crutchfield and Pontecorvo, 1969). Much of this irrationality is reflected in the dissipation of a sizable fraction of the available economic rent, a situation which results from the open-access nature of the fishery and legislated inefficiency. The remedy for this situation is to alleviate the open-access and inefficiency problem. Such alleviation would require the dissolution of rather formidable institutional problems. In the present paper, we examine the salmon problem from a slightly different vantage point than Crutchfield and Pontecorvo. We examine the salmon problem under the status quo; we do not consider the optimal amount of gear or its efficiency (this should not, however, be construed as reflecting any diminution in the importance of these problems); rather we consider, as an interim approach, whether it is possible, under the stringent condition of knowing in advance the structure of the run, to increase the value of the fish on the dock by optimally allocating the catch among the days of the run.

The traditional approach to salmon management might be considered, at the risk of several simplifications, as consisting of (1) forecasting the magnitude of the run; (2) setting an escapement goal and a catch implied by the forecast and the escapement; and (3) daily fishing closures and other devices which allocate the catch in varying quantities to the days of the run. The traditional approach, then, also involves an allocation of the catch to the days of the run. In the traditional approach, the allocations are usually based on the experience of management biologists. Although the objectives of their allocations are not always clearly and explicitly stated, there is a tendency for the primary objective of management to be simply the attainment of the escapement goal. Our approach is to use the theory of linear programming to advise on a non-intuitive optimum allocation of the salmon catch among the days of the run where the objective of management does not explicitly involve escapement. Rather, we develop our allocation strategy to maximize the value of the catch on the dock given a variety of constraints which include the necessity for a given number of fish to escape the fishery. The objective of maximizing the value of the fish on the dock and the constraints explicitly define the objectives of the management scheme.

[1] Contribution No. 333, College of Fisheries, University of Washington.

[2] Center for Quantitative Science and Fisheries Research Institute, University of Washington, Seattle, Wash. 98105.

[3] Fisheries Research Institute, University of Washington, Seattle, Wash. 98105.

Manuscript received October 1970.

We consider these problems in three additional sections. In the first, we describe the linear-programming allocation model, which we believe to be applicable, with simple modifications, to a variety of salmon management situations. In the second, we consider how the model might be applied to a run of salmon in the Naknek-Kvichak system of Bristol Bay, Alaska. As an example, we choose data from the 1960 run to that system and obtain an optimum allocation of large and small, male and female fish, on each day of the run to the daily catch. This optimum allocation served to maximize the value of the fish on the dock subject to constraints which ensured that the catch did not exceed the daily run, that the catch would be less than the cannery capacity, and that an "adequate" escapement, both in terms of the number of eggs and sex ratio, passed the fishery. Thus, in addition to managing the run by a non-intuitive optimum allocation and satisfying an escapement goal, we also considered the quality of the run in terms of its sex and age composition. In order, however, to achieve this optimum allocation we needed certain data on the structure of the run in advance and we also needed a mechanism by which we could select large and small male and female fish. It would most likely be impractical to have either a precise prediction of the daily run or an ability to select, with high precision, large or small, male or female fish. We show that even if we had the necessary data, a technique for precise selection of the various entities of fish, and maintained the 1960 escapement and sex-ratio conditions, optimum allocation would yield us a catch having a value of several hundred thousand dollars more than the actual catch. Thus given the cost of obtaining the necessary information to perform the optimum allocation and the constraints extant in 1960, it is questionable whether biological management could yield a better allocation than that which was obtained. This serves to re-emphasize the approach of Crutchfield and Pontecorvo, indicating that the system is most sensitive to variables which lie outside the objective and constraint equations specified in the present paper. On the other hand, our results show that it is possible, at least in terms of the model, to reduce the number of days during which the cannery operates and yet process the same number of fish. Furthermore as previously indicated, we constrained our example to fit the statistics of the 1960 run and thus we had, in our example, a nearly 1:1 sex ratio; but as we indicate later, we could have caught a considerably larger number of male fish and still would have had sufficient male fish in the escapement to ensure the efficient production of fertilized eggs. And finally the model was quite sensitive to decreasing the escapement but unfortunately there is little guidance in the literature which would indicate the optimum escapement for the Naknek-Kvichak system and furthermore there appears to be little hope of learning the magnitude, in the reasonably near future, of the optimum escapement for the Naknek-Kvichak system. Thus evaluation of the cannery processing time, catch problem, and relaxation of sex ratio and escapement constraints might result in an added value to the catch which would make some attempts at allocation practical. We also, in the second section, place some stress on interpretation of the shadow prices of the various variables in the problem. This is of interest to operations researchers because it provides an example, in addition to those conventionally used, of an application of the interpretation of the linear-programming primal-dual relation. The shadow prices are of interest to the fishery manager because from them it is possible to impute values to the various resources under the manager's control, and, in making a decision, the manager can thus consider these values which, as we show, are not always intuitively obvious. In the third and final section we conclude the paper with a general discussion of salmon management in a linear-programming setting.

MODEL

Most linear-programming models generally involve finding values X_i which maximize (or minimize) an objective function $\Sigma c_i X_i$, subject to a set of constraints each of which has the form $\Sigma \beta_i X_i \leq L_j$, where the inequality can be in either direction or can, in fact, be an equality.

The β_i's and the L_j's are constants appropriate to a particular problem. The details of the LP (linear-programming) procedure can be found in the many treatises on the subject (e.g., Gass, 1964) or in most texts on operations research (e.g., Hillier and Lieberman, 1967).

In our application of the LP model, we maximize the following objective function

$$Z = \sum_{i=1}^{M} \sum_{j=1}^{N} c_{ij} X_{ij}, \qquad (1)$$

where M refers to the total number of age-sex categories and N refers to the days of the run. The variable X_{ij} is the number of fish caught in the ith entity on the jth day of the run and c_{ij} corresponds to the value of the fish caught in the ith entity on the jth day (Table 1). The age-sex category classification results from the fact that salmon runs are comprised of a variety of age-groups. Because each age-group is usually of a different average size, the individuals in each age-group also have a different average value which we denote by c_{ij}. It should be mentioned that size is not the only criterion which can be used for classification. For example, in the Naknek-Kvichak run of Bristol Bay, the sex of the fish can also be used because within an age-group the male fish tend to be larger than the female fish and thus more valuable in terms of weight of fish-flesh; but, on the other hand, the eggs of the females are a valuable commodity and thus the per-pound value of females may be greater than the per-pound price of males. If the value of the fish were constant during the course of the run, we could replace the c_{ij} with c_i and the allocation problem would become rather uninteresting. But the value, however, does tend to vary during the course of the run. One reason for this is a deterioration of the quality of fish, as indicated by declining oil content and reduction in color intensity with the progression of the run. Another way in which c_{ij} could vary is that the average value of the fish on a particular day would tend to vary during the course of the run because of a within-entity trend in the average size of the fish during the course of the run; this, however, is not considered in the present paper. It is obvious that, if we had sufficient information, we could establish a large number of different c_{ij}'s.

TABLE 1.—Linear program model notation.

M	—	The total number of age-sex categories.
N	—	The total number of days in the run.
X_{ij}	—	The number of fish in the ith age-sex category which are caught on day j of the run.
c_{ij}	—	The value of a fish caught in the ith age-sex category on day j of the run.
R_{ij}	—	The number of fish in the ith age-sex category which run past the fishery on day j of the run.
K_j	—	The capacity, in numbers of fish, of the canneries on day j of the run.
K'	—	The total seasonal capacity of the canneries in numbers of fish.
W_{ij}	—	The number of fish of the ith age-sex category in the escapement on day j of the run.
a_i	—	The average number of eggs in each fish of the ith age-sex category.
T	—	The total number of eggs contained in the escapement and catch.
E	—	The minimum number of eggs required in the escapement.
M	—	The total number of males in the escapement and catch.
F	—	The average fecundity of the female age-sex categories, expressed in number of eggs.
H	—	The sex ratio desired in the escapement, expressed as the number of females per male.
L_i	—	The number of fish of the ith age-sex category desired in the season's escapement.
S_i	—	The number of fish in the total season run of the ith age-sex category.
$P(j)$	—	The proportion of the run that arrives by day j of the run.
$P'(j)$	—	The proportion of the run that arrives on day j of the run.

As indicated previously, equation (1) is maximized subject to a variety of constraints. For the salmon problem, the first set of constraints is rather obvious and constrains the catch, of any entity, on any day, to be less than, or equal to, the number of fish in that entity in the run. These constraints are of the form

$$X_{ij} \leqslant R_{ij}. \qquad (2)$$

X_{ij} is always $\geqslant 0$ and R_{ij} is the number of fish of the ith entity which run past the fishery on the jth day. There can be as many as $M \times N$ constraints of this form, but in some applications, either the number of entities or the number of days will be collapsed owing to either the nature of the problem or a lack of information. Note also we can easily "close" the fishery for

any entity or all entities on any day simply by setting the appropriate $R_{ij} = 0$.

The second set of constraints constrains the catch on any day to be less than the daily capacity of the canneries. Thus, we have the set of constraints,

$$\sum_{i=1}^{M} X_{ij} \leq K_j \qquad (3)$$

where K_j is the capacity of the cannery or canneries on the jth day. Another form of this constraint might be incorporated in situations such as in the Bristol Bay fishery, which has a short season, is remote from supply points, and thus has a finite seasonal capacity; these constraints can be expressed by

$$\sum_{i=1}^{M} \sum_{j=1}^{N} X_{ij} \leq K'. \qquad (4)$$

The constraint is redundant if $K' \leq \sum_{j=1}^{N} K_j$. and hence is only used when the season's capacity is less than the sum of the daily capacities, i.e.,

$$K' \leq \sum_{j=1}^{N} K_j.$$

The next set of constraints results from the need to ensure that an adequate number of fish escape the fishery and are thus permitted to spawn. We formulate this constraint in terms of the egg complement of the number of females escaping the fishery rather than the number of females escaping per se or the total number of fish (males and females) escaping.

In order to formulate this constraint set, we define T as

$$\sum\sum a_i W_{ij} + \sum\sum a_i X_{ij} = T \qquad (5)$$

where a_i is the average number of eggs in each fish in the ith entity, W_{ij} is the escapement of fish in the ith entity on the jth day and thus T is the egg complement of the escapement and the catch. Now if we need a minimum number of eggs to represent the escapement, a quantity which we denote by E, we must have

$$\sum\sum a_i W_{ij} \geq E. \qquad (6)$$

So substitution of (6) into (5) yields the constraint set conformable to the X_{ij}'s of our other constraints, viz.

$$\sum\sum a_i X_{ij} \leq T\text{-}E. \qquad (7)$$

We can see that by using the same reasoning we could construct a constraint set which would constrain the egg complement to be less than some maximum egg complement.

Our next constraint involves the sex ratio of the spawning fish. The utility of allowing a particular egg complement to escape the fishery could be negated by not allowing a sufficient number of males to escape for the purpose of fertilizing the eggs. In order to ensure that an adequate number of males escape the fishery, we formulate the necessary constraint by noting that

$$\sum W_j + \sum X_j = \mathcal{M} \qquad (8)$$

where in this particular equation the W's refer to the number of males in the escapement and the X's to the number of males in the catch and M to the total number of males in the run. Now to satisfy our constraint, we must have

$$\sum W_{ij} \leq \frac{E \times H}{F}. \qquad (9)$$

where the sum extends over all male entities and days of the run; F is the average fecundity of the female entities in the run, and H is the desired male to female sex ratio. Substitution of (9) into (8) then yields the desired constraint

$$\sum X_{ij} \leq \mathcal{M} - \frac{E \times H}{F}. \qquad (10)$$

This constraint can also be formulated in a variety of ways.

In addition to escapement goals established in terms of eggs and a sufficient number of males to fertilize the eggs, we desired to establish, for some sample problems, escapement goals in terms of total numbers of fish of each entity in the escapement; this would greatly simplify the simulation of the actual escapements for any historic salmon season. Hence, we developed the constraint

$$\sum_{j} W_{ij} \geq L_i \qquad (11)$$

where L_i is an escapement goal set for entity i which would ensure escapements identical with any historic year. To make (11) conform to our constraint set, we note that

$$\sum_{j} W_{ij} + \sum_{j} X_{ij} = S_i \qquad (12)$$

where W_{ij} and X_{ij} are the escapement and catch (respectively) of entity i on day j and S_i is the total season's run of entity i, we can substitute (11) into (12) and get the constraint in the proper form:

$$\sum_{j} X_{ij} \leq S_i - L_i. \qquad (13)$$

Thus a seasonal limit can be placed upon the catch of any entity i.

As indicated earlier, once the objective function and the constraints have been formulated, then optimization of the objective function, given the constraints, is a standard procedure outlined in some detail in the literature, and, with a computer facility, is a relatively simple task. There are, however, interpretations which are of further interest than the solution of the objective function. These interpretations rest in the primal-dual relationship of the LP problem.

In order to demonstrate this relation, we will denote a general form of the primal problem as

$$\text{maximize} \sum_{i=1}^{m} c_i X_i$$

$$\text{subject to} \sum_{i=1}^{m} a_{ij} X_i \leq b_j \qquad j = 1, \ldots, n \qquad (14)$$

where we have used slightly different notation than in the salmon problem, but the analogue between (14) and the salmon problem should, nevertheless, be quite clear. If (14) is the primal, then the dual of this primal is

$$\text{minimize} \sum_{j=1}^{m} b_j Y_j$$

$$\text{subject to} \sum_{j=1}^{m} a_{ij} Y_j \geq c_i \qquad i = 1, \ldots, m \qquad (15)$$

In the primal we are allocating scarce resources, the b_j's (number of fish in the run, cannery capacity, egg complement, and male fish), among the i activities (which consist in our problem of catching a particular entity of fish on a particular day). The intensity of the activity is X_i, the catch of the ith entity on the jth day and the "profit" per unit of the activity is, of course, c_j. It might be mentioned at this point that most LP computer codes provide as output the value of slack variables which in (14) is the difference between the right-hand side and the left-hand side of the constraint equations. The slack variables have a rather important interpretation for the salmon problem in that the slack variable in the run constraint (2) is the escapement; in the cannery constraint (3), it is the unused capacity of the cannery which we might want, in viewing the problem from a different context, to minimize; in the egg constraint (7), it is the number of eggs which are not caught that could be caught —another quantity which we might wish to minimize—and finally we have the slack variable associated with constraint (10) denoting the number of males which are not caught, but

could be caught, and which we might, similarly, wish to minimize. Thus, for example, we simultaneously derive, by virtue of the LP model, as we have formulated it, *both* the escapement and the catch.

Now, in the dual, we can place unit values on the scarce resources rather than on the levels of the activities, as in the primal. It is thus helpful, in making management decisions, to know the imputed unit value of a unit of cannery capacity, a large male fish, an egg, etc. These imputed values are commonly known as shadow prices and correspond to the optimal values of the Y_j's in (15); they will be discussed briefly in our interpretation of the salmon model. It should also be mentioned that we have slack variables in the dual formulation just as we had slack variables in the primal.

The dual slack variables can be viewed as opportunity costs in the sense that if we fail to meet a constraint, this is an opportunity foregone; and the dual slack variable then gives the value foregone by the "bad" management either of nature (that is, the vagaries induced in the system which are uncontrollable by the management agency) or of the management agency.

Finally, it is worth noting a feature of the shadow prices vis-á-vis the relation of the right- and left-hand side of the constraint equations. If in some solution of a particular problem, the right-hand side becomes equal to the left-hand side, then we say the constraint is binding. If the constraint is binding, then the shadow price has some positive value, namely the imputed value of an additional unit of scarce resource; but if, on the other hand, the constraint is not binding, then an additional unit of the resource is "free" within the bounds of the problem formulation—consequently the shadow price of the free resource is zero.

EXAMPLES BASED ON THE NAKNEK-KVICHAK RUN

As an example, we have decided to consider the implications of a LP approach to implementing the management framework of one of the most important salmon runs in North America, the sockeye salmon run to the Naknek-Kvichak system of Bristol Bay, Alaska. Our approach was to use the LP model described in the previous section employing actual data where available for the constraints and the objective function. Although we examined behavior of the model for several of the years for which we had data, we are presenting in this paper our partial analysis for the 1960 run only. Initially, we indicate how we assigned values to the various coefficients in the problem and then we give the actual examples.

First, we assigned values to the objective function (1) which is to be maximized. With respect to the number of entities in the objective function, there is a relatively large number of ocean-age groups represented in the Naknek-Kvichak run, but the very great majority are either the relatively large .3 ocean-age fish or the relatively small .2 ocean-age fish. Because, as we will see in subsequent paragraphs, the male fish are valuated differently than the female fish, we used four entities: male or female, .2 or .3 ocean-age fish.

Next, in order to assign values c_{ij} to each entity in the objective function according to the conventional per-fish management unit, we used the aforementioned observation that the male fish in each age group tend to be larger and hence more valuable than the female fish. On the other hand, the eggs which are contained in the females are processed into a caviar-type product, "sujiko," by Japanese firms in the Bristol Bay canneries. Thus, the females, because of the eggs which they contain, are more valuable than males of the same weight. Taking these factors into consideration and using an average ex-vessel value of \$0.25/pound, we have computed the average value for each entity. These calculations are set forth in Table 2 which shows, among other things, that the added value of eggs tends to offset the reduced value of females relative to males of the same age class.

As indicated previously, the \$0.25/pound is an *average* value and it should be emphasized at this point that it is not a computed average since generally speaking a fixed price is paid for fish throughout the season. But as we indicated earlier, some fish are certainly more

TABLE 2.—Computations used to determine the value of each entity classification for the model.

Entity	Sex	Age	Average weight[1]	Average no. of eggs[2]	Average value c_i
			Lb.	*Number*	*$*
1	Male	2-ocean	5.1	--	1.28
2	Male	3-ocean	7.4	--	1.85
3	Female	2-ocean	4.5	3,700	1.38
4	Female	3-ocean	6.2	4,384	1.84

[1] With the price of salmon at $0.25/pound, the value of each entity can be calculated as follows:

entity 1 — 5.1 X $0.25 = $1.28;
entity 2 — 7.4 X $0.25 = $1.85;
entity 3 — 4.5 X $0.25 = $1.13;
entity 4 — 6.2 X $0.25 = $1.55.

[2] With the price of salmon eggs at $0.50/pound, the additional value of each female entity can be calculated as follows (it should be noted that eggs were not processed in 1960):

entity 3 — 3,700 eggs X .061 g/egg ÷ 453.6 g/lb X $0.50 = $0.25

entity 4 — 4,384 eggs X .061 g/egg ÷ 453.6 g/lb X $0.50 = $0.29.

valuable than others. Thus, we deduced that this fixed price must reflect an average value and we note, parenthetically, the important point that the bias and precision (we take the liberty of using these terms in the statistical sense even though the estimation procedure may not be statistical in nature) with which this average is estimated is a subject of significance to the management of the salmon stocks.

In addition to the value of salmon differing among entities, the value of salmon usually deteriorates within an entity during a season. Thus, even though a fixed price is paid for salmon during a season, the value decreases owing to a reduction in quality. For example, the value of pink salmon may be 25 % less near the end of the run than near the beginning of the run. The decline in value of red salmon is not so severe, amounting to a range of about $0.03/pound from the beginning to the end of the season. (While a few cents decline in value during the course of the season may seem to be a negligible quantity, we must remember that this factor must be multiplied by the several pounds in weight of each fish and the several million fish that are involved in the value reduction.) So just as we deduced $0.25/pound to be an average price among entities, we must likewise deduce that the values tabulated in Table 2 are average values for each entity for the season. In the Naknek-Kvichak run, which usually begins around June 27 and ends around July 15, the decline in value appears to be centered on July 4.

In order to arrive at a unique allocation, we must deduce how the c_{ij}'s for each of the j days of the run differ from the average of the c_{ij}'s listed in Table 2. The ideal way of doing this would be to develop a model which is descriptive of the value change during the run. Unfortunately, we have no information upon which to base such a model, so we used three arbitrarily chosen functions to describe the day-to-day value change of the salmon. An example of these is shown in Figure 1.

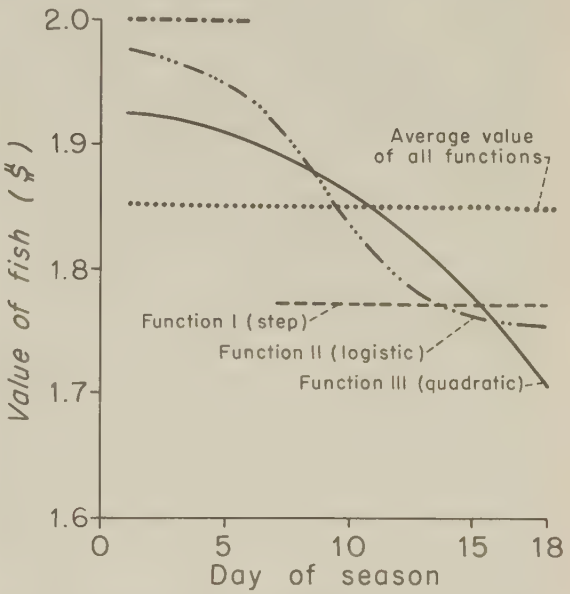


FIGURE 1.—Value functions as objective function coefficients in the linear-programming model for entity 2 (large male fishes).

Next we needed to determine the quantity, in the objective function, of N, the number of days of the run. We utilized an empirical equation presented by Royce (1965) to obtain both N and the daily run for each entity R_{ij}. The function Royce used for each of several years to describe the temporal change in the Naknek-Kvichak catch is

$$P_k(j) = \frac{1}{1 + e^{-(a_k + b_k j)}} \qquad (16)$$

where k specifies the year of the run, a_k and b_k are constants, j is time in days, and $P_k(j)$ is the cumulative proportion of the total catch. In order to choose N, we defined the fishing season to be those days for which $.05 \leqslant P(j) \leqslant .95$ and the difference between the initial and closing day was, to the nearest integral value, set equal to N.

We also used expression (16) to obtain R_{ij} from $P'_k(j) = P_k(j) - P_k(j-1)$ and then $R_{ij} = P'_k(j)\ S_i$, where S_i is the number of fish of the ith entity in the run during the year under consideration. The assumptions involved in obtaining the R_{ij}'s are (1) the catch is proportional to the "average" run as defined by the fitted curve (16); and (2) R_{ij} is proportional to $R_{.j}$. It should also be mentioned that our R_{ij}'s are certainly different from the traditionally used R_{ij}'s because the latter are based on counts made several days after the fish enter the fishery area. This, however, is not important in the allocation whereas the relative daily size of the run is important. We feel that these assumptions are reasonable for the present model until more accurate information can be obtained on the behavior of the fish in the run.

On some occasions, the catch in Bristol Bay is limited by the cannery capacity. This capacity can be, of course, adjusted by the industry, but it appears that, according to Mathews (1966), 1 million fish per day is a maximum capacity and we used this value in constraint equation (2). It would appear that the most important assumption implicit in the nature of this constraint is independence among the days; that is to say, we assume that processing a certain number of fish on one day does not affect the processing capacity on the next day. A second assumption is that the maximum capacity is not dependent upon the average size of the fish processed. There is some question, when the cannery operates near peak capacity, as to the effect of overtime payments to cannery employees and to the effect of processing large numbers of fish on the quality of the pack.

For our example, of the 1960 run, the total season constraint was not reached and so this constraint had no effect on any of the examples which we present. It is relevant to note, however, that if this constraint is needed, then the maximum number of fish ever processed (up until 1969) in the Naknek-Kvichak system was 19.1 million.

The next constraint is the escapement constraint. Despite the fact that the level of escapement has, for salmon stocks, been the primary management criterion, there is very little documentation on the proper escapement level for many systems. The latest synthesis of the extensive work on the Naknek-Kvichak system is addressed to the problem of optimum escapement in that particular system as well as others (Burgner, DiCostanzo, Ellis, Harry, Hartman, Kerns, Mathisen, and Royce, 1969), but unfortunately no advice on optimum escapement is given for the Naknek-Kvichak. Another study implies, on the basis of limited data, that escapements beyond about 10 million fish will not result in any increased productivity of smolts (Mathisen, 1969: Fig. 6), and thus if we make a simplifying assumption and assume that marine survival rates are independent of density, we can further assume that an increased return will not accrue from an escapement larger than 10 million fish (very roughly 20 billion eggs).

Despite the fact that we do not "know" the optimal minimal escapement for the Naknek-Kvichak system, it is clear that there must be some level which is, in some sense, optimal. This statement must, of course, be tempered with our knowledge of the cyclical nature of the run.

Because of our uncertainty, we examined the model under a variety of escapement conditions but keeping under each set, what would appear to be, according to studies by Mathisen (1962), a conservatively high male-to-female sex ratio of at least one male for every three females. We found in general, as one might expect, that as we increased escapement we decreased the value of the catch. The objective function was quite sensitive to this manipulation, focusing again upon the need for a well-defined escapement policy. What is not so obvious, however, as we will see subsequently, is that as we change the escapement level, we can obtain considerable changes in the imputed values of the var-

ious entities. The 1960 run had an escapement of 31 billion eggs. We estimate that this escapement was partitioned among the entities as follows:

Entity 1, 57.5 % or 8,136,000 fish escaping
Entity 2, 43.4 % or 210,000 fish escaping
Entity 3, 74.8 % or 7,964,000 fish escaping
Entity 4, 30.8% or 389,000 fish escaping

It is interesting to note that in addition to 8,350,000 females which were estimated to have escaped in 1960, there were, in addition, 8,300,000 males that escaped, signifying a nearly 1:1 sex ratio.

Our general approach in presenting our particular 1960 run example was to concentrate upon simulating the actual events in 1960 by using the above run data in equations (13) and (7), the fecundities listed in Table 2, and the logistic value function. We also present some results where we effectively drop equation (13) and replace it with equation (10) using a low escapement of 5 billion eggs in order to demonstrate the sensitivity of the model to various escapement goals.

In Figures 2, 3, 4, and 5, we depict the optimum allocation of the catch which we obtained using the actual 1960 escapement data. The figures also include the smoothed catches derived from Royce's work. From these figures,

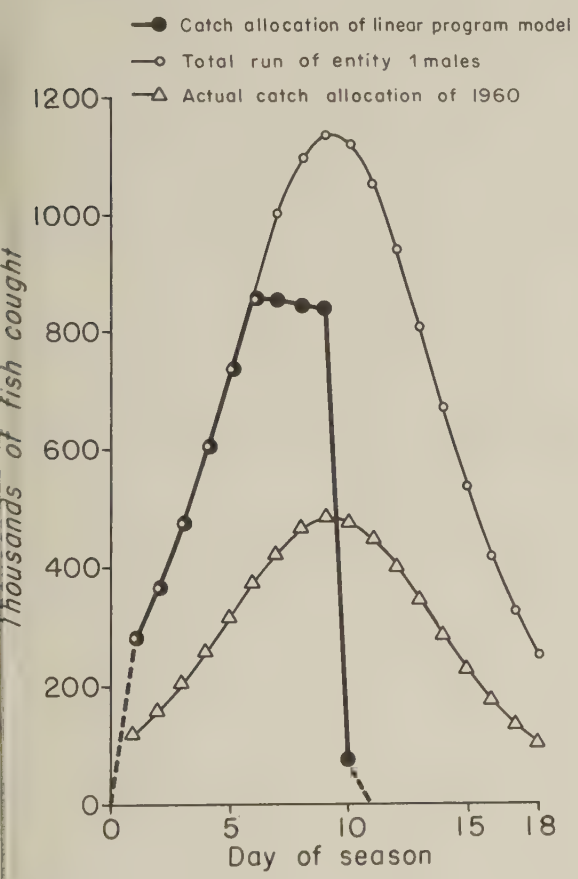


FIGURE 2.—Year 1960 small male catch allocations (entity 1). The actual catch allocations are the smoothed average values obtained from Royce (1965).

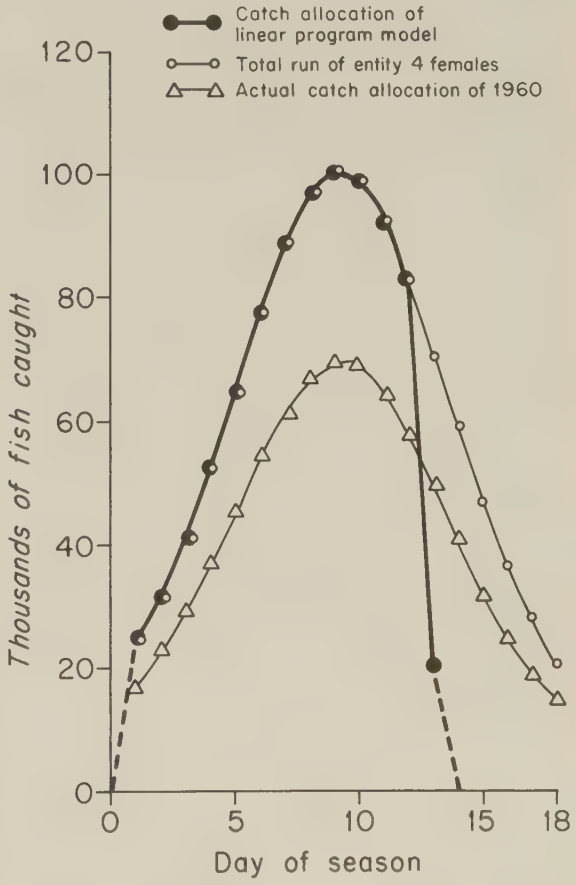


FIGURE 3.—Year 1960 large female catch allocations (entity 4). The actual allocations are the smoothed average values obtained from Royce (1965).

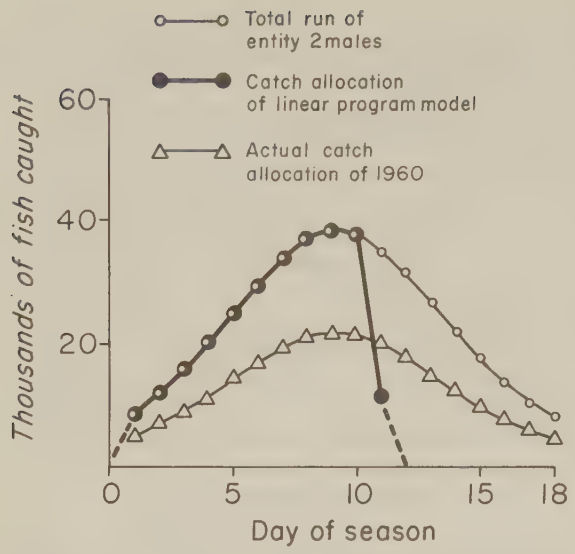


FIGURE 4.—Year 1960 large male catch allocations (entity 3). The actual catch allocations are the smoothed average values obtained from Royce (1965).

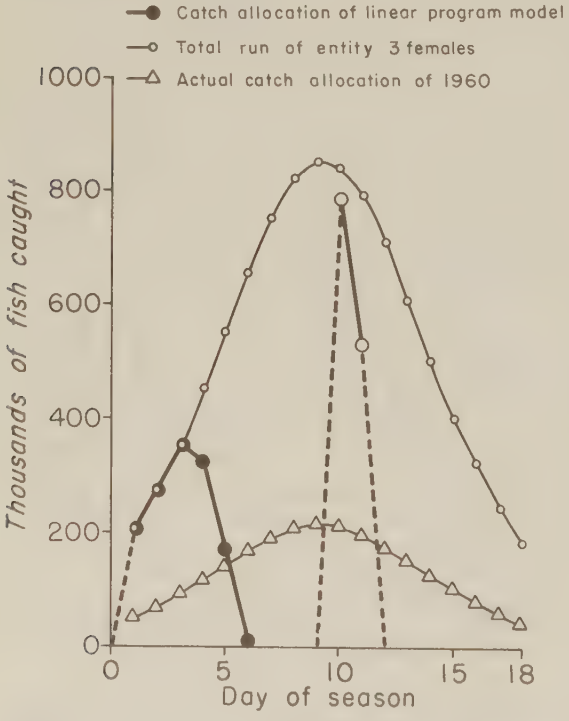


FIGURE 5.—Year 1960 small female catch allocations (entity 3). The actual catch allocations are the smoothed average values obtained from Royce (1965).

we can observe various properties of the optimally allocated catches. For example, in Figures 3 and 4, the catch allocation of the early season is identical to the number of fish in the run. These large male and large female fish are more valuable than the smaller fish and most valuable in the early part of the season because of the value function. Hence, all the large fish available are caught until the season's limit for each of the large-fish entities has been reached. We must be cautious here, however, because as we point out in our discussion, there is a possibility of modifying the characteristic of the run by selective fishing.

In order to interpret Figures 5 and 6, we must realize that the next most valuable fish are the small females. The difference in price between small females and small males increases through the season. This owes to the fact that small females weigh less than small males and thus decrease in value less towards the end of the season. (Recall that the small females are more valuable than small males only because of the eggs which they contain.) We have assumed that the value of the eggs is constant throughout the season.

The optimal solution shows that the cannery is at capacity from days 4 to 10 with as many small males being caught through day 6 as are available, and as many additional small females being caught as the cannery can process. On days 7 to 9 there are enough fish exclusive of the small females to bring the cannery to capacity. However, by day 10, the season's limit of small males has been caught and small females must be caught to keep the cannery at capacity. It must be remembered that the price difference between females and males is greater later in the season. For example, if a small female is caught instead of a small male on the 6th day of the season, the increased profit is \$1.430 — \$1.337 = \$0.093, where the figures are the value of small females and small males, respectively, on day 6 for the logistic value function which we used. But if a female is caught instead of a male on day 10, the increased profit is \$1.371 — \$1.270 = \$0.101, for the same value function. Hence, while the cannery is being operated to capacity and since the total num-

ber of fish of any entity is fixed by the seasonal limit, it is more profitable to catch the small, less valuable, males earlier in the season, which may seem contrary to the intuition. The implications of the optimal allocation are considered in the discussion and conclusions section.

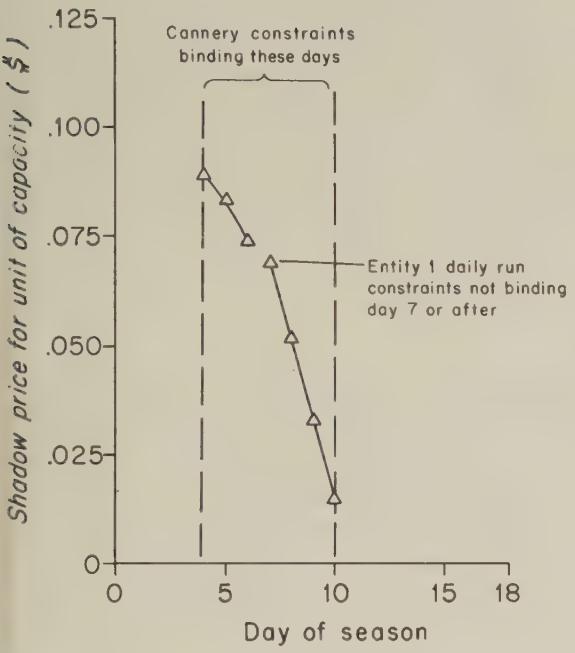


FIGURE 6.—Shadow prices for daily cannery constraints —an example in which seasonal entity limits are imposed.

As indicated previously, the shadow prices are useful in considering various management implications. We consider, as examples, the egg shadow prices, the cannery shadow prices, and the run shadow prices. It might be mentioned somewhat parenthetically that although the shadow prices can be explained and interpreted as in the following paragraphs, in the LP calculation, they are not found in this manner. The shadow prices are calculated as simultaneous results of an iterative solution procedure and include the results of previous iterations. In fact, the shadow prices associated with each constraint at the end of each iteration are used to determine how to manipulate the matrix to improve the objective function in the subsequent iteration. With very involved problems, it might not be possible to examine the shadow prices as below, and in any case, only a good deal of insight into the problem permits their delineation in this manner. One other caution is that while applying the following equations to determine a total increase in profit, care must be taken to see that the same constraints remain binding or nonbinding. Once a constraint changes from binding to nonbinding, the solution basis changes, also changing the relationships between variables and constraints.

The increase in value of the objective function corresponding to a relaxed egg constraint (allowing one more egg in the catch) is the shadow price associated with the egg constraint. The shadow price is dependent upon which, if any, of the constraints in the LP model are binding. If the egg catch constraint[4] is not binding, indicating that the value of this catch scheme is not being limited by this constraint, then the shadow price associated with the egg constraint is zero. If the egg catch constraint is binding, shadow prices associated with the egg constraint, depending upon which of the other constraints are effective, can be calculated.

The imputed value of an egg, its shadow price, thus depends on whether the cannery constraint is binding. Now, if the cannery constraint is binding on day j (indicating that the maximum number of fish are being processed and the addition of a single or marginal fish to the processed catch requires that a fish already existing in the catch must, to maintain the constraint, be replaced by the marginal fish), and the entity 4 run constraints are binding throughout the season (indicating that all large females are caught), then the shadow price associated with the egg catch (ESP) constraint is

$$ESP = (c_{3,j} - c_{1,j})/3{,}700$$

where day j is a day on which the entity 3 run

[4] Although the egg constraint arose from a minimum egg escapement requirement, it was necessary to convert it to a maximum egg catch requirement constraint for use with the LP model, as was described earlier. It is convenient to think of the constraints in terms of "egg catch" for purposes of discussing the shadow prices.

constraint is not binding, i.e., there are entity 3 females available to be caught. The formula indicates that allowing the catch of one more egg essentially allows the catch of 1/3,700 of an entity 3 female which requires the escapement of 1/3,700 of some other fish since the cannery constraint is binding. The fish to be included in the escapement is, of course, the low-valued entity 1 male.

If the cannery constraint on day j is binding, but there is a day when the entity 4 run constraint is not binding, and since the value of a large female per egg is greater than the value of a small female per egg, the value of allowing the catch of an additional egg is

$$ESP = (c_{4,j} - c_{1,j})/4{,}384$$

where day j is a day on which the entity 4 run constraint is not binding.

If the cannery constraint is not binding on day j then catching additional females does not require the escapement of an equal number of males, or, in other words, the addition of the marginal fish does not require the release of a fish extant in the catch. If, however, all the entity 4 run constraints are binding through the season, then

$$ESP = c_{3,j}/3{,}700$$

where day j is a day on which the entity 3 run constraint is not binding. Or, if an entity 4 run constraint is not binding on day j and again since the value of a large female is greater than that of a small female,

$$ESP = c_{4,j}/4{,}384$$

The next shadow price that we will evaluate is the increase in value of the ability to process an additional or marginal fish. The imputed value of processing a marginal fish is called the shadow price of the cannery constraint (CSP), and we must remember that this marginal fish only has an imputed positive value if the cannery constraint is binding. In other words, we can impute a value to an additional unit of cannery capacity. Following the format above, the shadow prices for the cannery constraint can be outlined. For emphasis, we repeat again that if the cannery constraint is not binding, indicating that the value of this catch scheme is not being limited by this constraint, then the shadow price associated with the cannery constraint is zero. If the cannery constraint is binding, shadow prices associated with the cannery constraint, given which other constraints are effective, can be determined.

The objective function will be increased by an amount equal to the value of the additional fish which is included in the new catch scheme (the scheme arising from relaxing the cannery constraint), and hence the most valuable fish will be caught. If run constraints are not binding, the shadow price is

$$CSP_j = c_{2,j}$$

since the large males are the most valuable. As the run constraints become binding for the more valuable entities, the shadow price of the cannery constraints is equal to the value of the most valuable entity available.

If, for example, the egg catch constraint is binding as well as the entity 2 run constraint, the shadow price of the cannery constraint is

$$CSP_j = c_{4,j} - \left(\frac{4{,}384}{3{,}700}\, c_{3,j}\right).$$

The modification of the equation assures that enough eggs will escape (via entity 3 female) to enable the catch of the more valuable entity 4 female.

To emphasize the effect of reduced escapements and concomitant binding egg catch constraints, we employed the 1960 run model but dropped equation (13) and used an effective escapement of 5 billion eggs in equation (10). If the egg catch constraint is binding as well as entity 4 run constraints, the only fish available for catching are the entity 1 (small males), since no more females can be caught without violating the egg catch constraint. Hence

$$CSP_j = c_{1,j}.$$

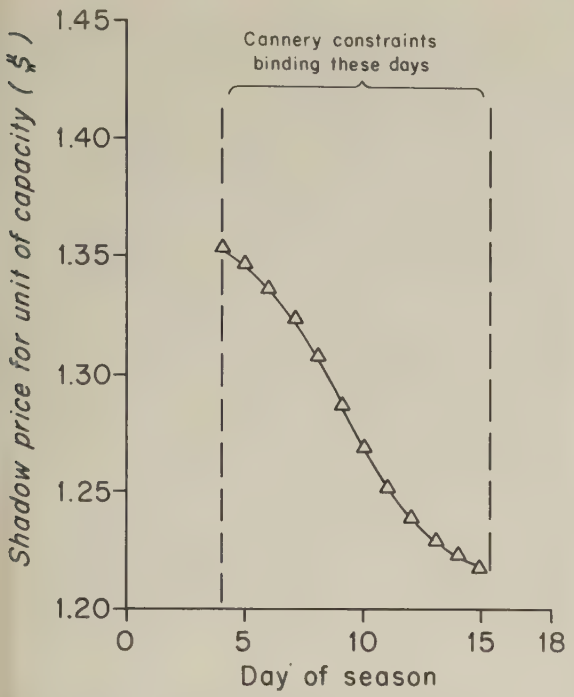


FIGURE 7.—Shadow prices for daily cannery constraints —an example in which seasonal entity limits are not imposed.

As an example of this situation where we have an escapement of 5 billion eggs, consider Figure 7, where the curve representing the cannery shadow prices is exactly the value function curve for entity 1 males. If, however, we contrast the 5 billion egg constraint situation with the actual 1960 run where the seasonal limit constraints are binding for all entities, then the improvement in the objective function attributed to the one unit of increased cannery capacity will only be equal to

$$CSP_j = c_{ij} - c_{ij^*}$$

since to catch a fish of entity i on day j another fish of entity i must be released on day j^* $(j^* \neq j)$ to avoid breaking the seasonal limit constraint. Figure 6 gives an example of this situation. The particular example is taken from the LP model using the logistic value function and actual escapements of 1960 by entity (thus the seasonal limit constraints). In this case, the total number of fish processed remains the same (since season limits are binding for all entities already), but processing a fish earlier in the season can result in an increased profit because of the shape of the value-function curve.

The implications of Figure 6 are quite subtle. In Figure 6, until day 4, the cannery is not at capacity, and hence there is obviously no value associated with an increased unit of capacity. All fish are included in the catch allocation in the early-season, high-value situation. On day 4 the cannery is at capacity and some fish must be included in the escapement (excluded from the catch). Intuitively, we would expect the highest value fish to be caught. This is partly reflected by the continued catch of all entities 2 and 4 fish (the large males and females), but, keeping in mind the fact that catches in all entities are being limited by the seasonal limit constraints and the idea of the decreasing price differential between entity 3 and entity 1 fish, entity 3 fish become part of the escapement. This says that on days 4 to 6, an increase in the capacity of the cannery will result in an entity 3 fish being caught on that day and a less valuable entity 3 fish released later in the season (to avoid breaking the season's limit constraint). We can see in Figure 5 that the last day on which an entity 3 fish can be released is day 11. The value of an entity 3 fish on day 4 is \$1.445, the value of an entity 3 fish on day 11 is \$1.356. Hence we would expect to gain exactly \$0.089 by increasing the cannery capacity by one unit on day 4. Checking Figure 6, we see this is exactly what the graph shows for day 4. Days 5 and 6 can be calculated similarly.

On days 7 to 10, entity 1 daily run constraints are no longer binding, and hence an additional unit of cannery capacity could result in an entity 1 fish being caught on day 7. From Figure 5 the least valuable entity 1 fish in the catch scheme is on day 10, and one of these would go into the escapement. The increased value is

$$c_{1.7} - c_{1.10}$$

or

$$\$1.324 - \$1.270$$

or a profit increase of \$0.054. In Figure 6, the

shadow price of the cannery constraint on day 7 is shown as \$0.069. Note, however, that when an entity 1 fish is released on day 10 that the cannery is no longer at capacity on day 10, hence an entity 3 fish could be caught on day 10 if an entity 3 fish was released on day 11. This is an additional contribution to the shadow price for day 7 of

$$c_{3,10} - c_{3,11}$$

or

$$\$1.371 - \$1.356$$

or a profit increase of \$0.015. Adding this to the value of catching an earlier entity 1 fish gives \$0.054 + \$0.015 = \$0.069, and this is exactly what is shown for day 7 in Figure 6. Values for days 8 to 10 can be calculated similarly.

Next let us consider the run shadow prices (*RSP*). The increase in value of the objective function corresponding to relaxed run constraints allowing one more fish of any entity in the catch is the shadow price of that run constraint. If the cannery constraint is not binding, if seasonal run constraints are not used or are not binding, and if egg catch or male escapement constraints are not binding, there is no restriction other than the run constraint limiting the catch. Since there is a run constraint for each entity and day

$$RSP_{ij} = c_{ij}.$$

However, if the cannery constraint is effective on day j

$$RSP_{ij} = c_{ij} - c_{i^*j}$$

where entity i^* ($i^* \neq i$) is the fish that must escape to allow the catch of entity i since the cannery is already processing as many fish as possible. And if the egg catch constraint and/or the male escapement constraint is binding, appropriate numbers of fish must be released when additional fish are caught. As an example of the behavior of the system when the 5 billion egg constraint is used, consider Figure 8. As shown in Figure 8, daily cannery constraints are binding from days 4 to 15, and, in addition,

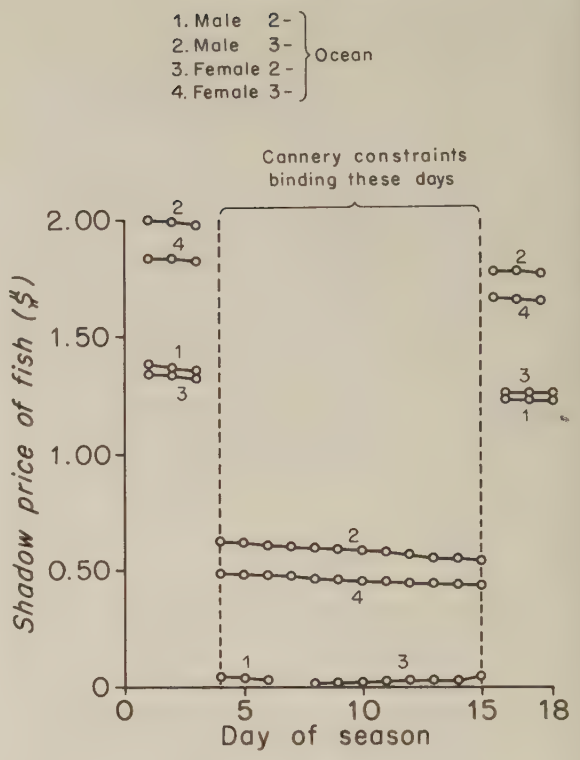


FIGURE 8.—Shadow prices for daily entity run constraints—an example in which seasonal entity limits are not imposed.

the egg catch constraint is binding. Although it is not illustrated in the figure, it is essential, in understanding the problem, to realize that the entire escapement satisfying the egg escapement constraint is made up of small (entity 3) females, and that the entire escapement satisfying the male escapement constraint is made up of small (entity 1) males. Also, all fish of all entities are in the catch scheme on days 1 to 3 and 16 to 18 (all days on which the cannery constraints are not binding).

In Figure 8, on days 1 to 3, the cannery constraints are not binding; and since entity 2 escapement is not being used to satisfy any constraints of any form, the run shadow prices on days 1 to 3 will be equal to the value function (this can be checked with the values listed in Appendix Table 2). In addition, since the male catch constraint is not binding, the run shadow price for entity 1 is also equal to its value func-

tion for the first 3 days of the season. This is not true for entity 3 or 4 since the egg-catch constraint is binding, indicating that no more eggs can be "caught" without breaking the constraint. Hence, when an entity 4 female is caught on a day 1 to 3 (catching 4,384 eggs), 4,384 eggs must be released on some other day of the season. This can be done with the smallest loss by releasing 4,384/3,700 entity 3 females (entity 3 females have 3,700 eggs). To further decrease the loss, the above fractional parts of an entity 3 should be released on a day on which there are entity 1 or 2 available to be caught, since this will keep the cannery constraint intact and not violate the male catch constraint since it is not binding. Remembering that the price differential between entity 1 and entity 3 increases over the season, it is desirable to catch the additional entity 1 fish as early as possible, which is on day 7. Then (note that all of the larger males are already in the catch scheme):

$$RSP_{4,1} = c_{4,1} - \frac{a_4}{a_3} c_{3,7} + \frac{a_4}{a_3} c_{1,7}$$

$$= \$1.941 - \frac{4{,}384}{3{,}700} (\$1.419) + \frac{4{,}384}{3{,}700} (\$1.324)$$

$$= \$1.828,$$

which can be seen on the graph as the shadow price for entity 4 day 1. To calculate the value of the run shadow price for entity 3 in days 1 to 3, we must realize that catching an entity 3 female requires the release of a female some other time during the season in order to avoid breaking the egg catch constraint. Since the entity 3 females are of lesser value than the fractional part of an entity 4 female which must be released to account for the 3,700 extra eggs caught, the release of this fish on a day on which there are entity 1 fish available will lessen the loss. As before, the price differential between entities 1 and 3 is smaller early in the season, and the earliest date on which an entity 1 male is available is day 7. For example,

$$RSP_{3,1} = c_{3,1} - c_{3,7} + c_{1,7}$$

$$= \$1.453 - \$1.419 + \$1.324$$

$$= \$1.358,$$

which is the value shown in Figure 8.

The run shadow price for entity 1 day 4 results from the catch of entity 1 on day 4 requiring the release of entity 3 (to avoid breaking the cannery constraint) which, in turn, allows the catch of an entity 3 and the release of an entity 1 on day 11 (the last day on which there are entity 3's *not* in the catch scheme). Essentially, what we have done is to exchange the catch of entity 1 and entity 3 for a time when the price differential is more favorable.

$$RSP_{1,4} = c_{1,4} - c_{3,4} + c_{3,7} - c_{1,7}$$

$$= \$1.353 - \$1.445 + \$1.419 - \$1.324$$

$$= \$0.003,$$

which is the value shown in Figure 8. Run shadow prices for entity 1 days 5 and 6 can be figured similarly. For entity 1 days 7 to 15, the daily run constraints are not binding, and hence, the run shadow prices are zero.

Run shadow prices for entity 2 days 4 to 15 (still referring to Figure 8) can be calculated as the difference between the value of an entity 2 and entity 1 on those days. The entity 1 must be released in order to satisfy the cannery constraints for those days. In addition, for days 4 to 6, calculating the value of this new availability of an entity 1 released in order to catch an entity 2 is essentially the same situation as calculating the shadow price of entity 1 on those days, and hence, the value of the scheme and the run shadow price is increased by that additional amount.

Run shadow prices for entity 3 days 4 to 7 in Figure 8 are zero since the run constraints of entity 3 for those days are not binding. For entity 3 days 8 to 15, they can be calculated as follows: If another entity 3 is caught on day 8, an entity 1 must be released on day 8 to maintain the cannery constraints. The catch requires the escape of an entity 3 fish on another day to maintain the egg catch constraint. In turn, if

the release of the entity 3 is on a day which a male entity is available, that entity can be caught without breaking the cannery constraint, e.g.,

$$RSP_{3,8} = c_{3,8} - c_{1,8} - c_{3,7} + c_{1,7}.$$

(Note that day 7 is the *first* day on which there is a male entity not already in the catch scheme, and hence, the price differential is smallest.)

$$RSP_{3,8} = \$1.404 - \$1.307 - \$1.419 + \$1.324$$
$$= \$0.002,$$

which is that value shown in Figure 8.

Run shadow price for entity 4 days 4 to 15 can be calculated by releasing and catching the fractional parts 4,384/3,700 of entities 3 and 1 as required to maintain cannery and egg catch constraints, in a manner similar to that for days 1 to 3. The run shadow prices for the male entities for days 16 to 18 (those days after the cannery constraints are no longer binding) are simply equal to the value of those entity-days, since they are not involved in satisfying any constraints of any form. The run shadow prices for the female entities on these days are a little more difficult to arrive at, since as they are caught, an equal number of eggs must be released, resulting in a slack cannery constraint which can be filled by catching additional male entities when available.

Consider, in contrast, Figure 9, where the run shadow prices are shown for a case in which we used the actual escapement for the 1960 run in constraint equation (13). The seasonal limit constraints are binding for all entities in this example. It follows that in every case when calculating a run shadow price for an entity day, the inclusion of an additional unit of any entity on that day implies that a unit of that entity must escape on some other day of the season to maintain the equality of the seasonal limit constraint for that entity.

In Figure 9, shadow prices are plotted for the daily run constraints for the particular example in which seasonal limits were imposed to achieve the actual escapements of 1960. Neither the egg catch constraint nor the male catch constraint was binding; the seasonal limit constraint was binding for each entity. Cannery constraints were binding from days 4 to 10, as indicated on the figure. In calculating the run shadow price for any entity on any day, note that whenever an additional fish is included in the catch scheme, a fish of that same entity must be eliminated from the catch scheme on some other day in order to maintain a valid seasonal limit constraint for that entity. Thus, for entity 1 days 1 to 3, the run shadow price can be calculated as the value of a fish included on the day being considered minus the value of the lowest valued fish of entity 1 in the catch scheme which must be released to keep the constraints

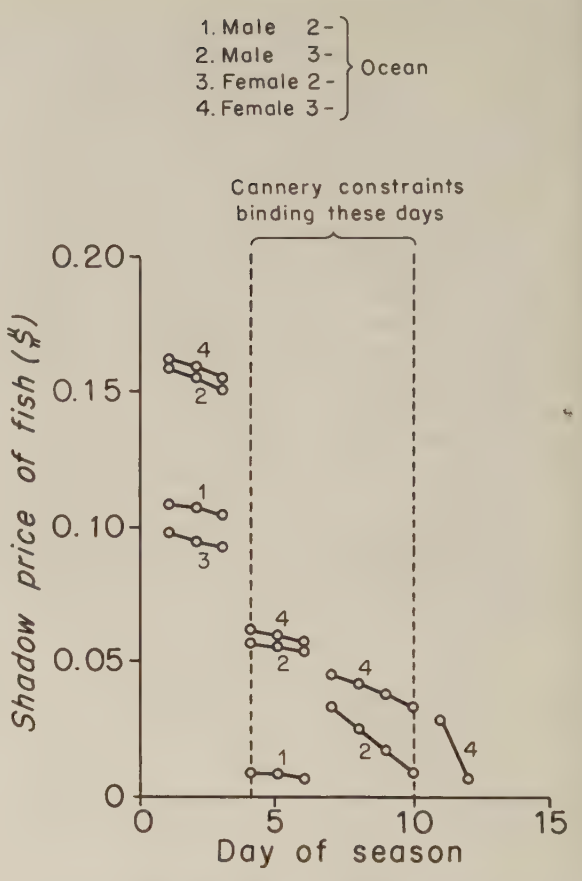


FIGURE 9.—Shadow prices for daily entity run constraints—an example in which seasonal entity limits are imposed.

effective. If this low-valued fish is released on a day on which the cannery constraint was binding, then the cannery constraint is no longer binding and a fish of another entity can be caught on that day if a fish of that other entity is available. For example,

$$\begin{aligned} RSP_{1,1} &= c_{1,1} - c_{1,10} + c_{3,10} - c_{3,11} \\ &= \$1.362 - \$1,270 + \$1.371 - \$1.356 \\ &= \$0.107, \end{aligned}$$

which is the value shown in Figure 9. The run shadow prices for entities 2 to 4 on days 1 to 3 are simply calculated as the value of the entity on that day minus the value of that entity on the lowest priced, and hence, last day on which it is included in the catch scheme. For example,

$$\begin{aligned} RSP_{3,1} &= c_{3,1} - c_{3,11} \\ &= \$1.453 - \$1.356 \\ &= \$0.097. \end{aligned}$$

Checking Figure 5, we see that day 11 was the last day on which entity 3 fish were caught, and Figure 9 shows that the value ($0.097) is correct.

Run constraints for entity 3 are not binding after day 3, so run shadow prices associative are zero.

To obtain the run shadow price for entity 1 for days 4 to 6, one may, for example, subtract from the value of entity 1 day 4, the value of entity 3 day 4 (which must be released to maintain the daily cannery constraints), subtract the value of entity 1 day 10 (which must be released to maintain the season entity 1 limit), and add the value of entity 3 day 10 (which can be caught since an entity 1 has been released on day 10); or

$$\begin{aligned} RSP_{1,4\text{-}6} &= c_{1,4} - c_{3,4} - c_{1,10} + c_{3,10} \\ &= \$1.353 - \$1.445 - \$1.270 + \$1.371 \\ &= \$0.009, \end{aligned}$$

which can be seen in Figure 9.

Run shadow prices for entities 2 and 4 for days 4 to 6 are similar. For illustration, entity 4 day 4 will be calculated:

$$RSP_{4,4} = c_{4,4} - c_{3,4} - c_{4,13} + c_{3,11}.$$

That is, the run shadow price of entity 4 day 4 equals the value of entity 4 day 4 less the value of entity 3 day 4 (to preserve the daily cannery constraint) less the value of entity 4 day 13 (to preserve the seasonal entity 4 limit) plus the value of entity 3 day 11 (since an entity 3 day 4 was excluded, this will be within the entity 3 seasonal limit constraint). Thus

$$\begin{aligned} RSP_{4,4} &= \$1.930 - \$1.445 - \$1.780 + \$1.356 \\ &= \$0.061. \end{aligned}$$

This is the value shown in Figure 9.

The run shadow prices for entity 1 after day 7 are zero since the daily run constraints are no longer binding. For entities 2 and 4 days 7 to 10, the run shadow prices can be calculated similarly. For example,

$$RSP_{2,10} = c_{2,10} - c_{3,10} - c_{2,11} + c_{3,11}.$$

That is, the run shadow price of entity 2 day 10 equals the value of entity 2 day 10 less the value of entity 3 day 10 (to preserve daily cannery constraints) less the value of entity 2 day 11 (the last day on which entity 2's are caught and, hence, the cheapest entity 2 which can be released to preserve the seasonal limit) plus the value of entity 3 day 11 (since an entity 3 was released on day 10, this will not fracture the seasonal entity 3 limit constraint). Thus

$$\begin{aligned} RSP_{2,10} &= \$1.836 - \$1.371 - \$1.812 + \$1.356 \\ &= \$0.009, \end{aligned}$$

which is shown as the correct value in Figure 9.

The run shadow prices for entity 4 on days 11 and 12 are easily calculated since the cannery constraints are no longer binding and this is the only entity being caught after day 12. Hence,

$$\begin{aligned} RSP_{4,11} &= c_{4,11} - c_{4,13} \\ &= \$1.808 - \$1.780 \\ &= \$0.028. \end{aligned}$$

It is interesting to note that the run shadow prices of entity 4 throughout the season are higher than those of entity 2 (see Figure 9), even though the value for an entity 4 is less, for any given day, than the value of entity 2. This is due to the optimal catch scheme which has catches of entity 4 until day 13, while entity 2 catches are only made until day 11. The effect is that when an additional fish of an entity is caught early in the season (requiring the release of a fish of the same entity later in the season), the entity 2 fish released is from day 11 of value \$1.812, the entity 4 fish released is from day 13 of value \$1.780. The value of the entity scheme then, decreases least (proportionately) for releasing the entity 4 fish.

DISCUSSION AND CONCLUSIONS

It can be seen that the linear-programming (LP) approach to salmon management, as with all other modelling approaches, involves a variety of assumptions which are either intrinsic to the procedure or to the way the procedure is applied to real-world problems. We have gone into some detail to show the richness of interpretations that the salmon model affords, and we believe that the application of this procedure to salmon management will provide increased guidance to and widen the spectrum of possible management decisions. The procedure we have used for the Naknek-Kvichak run is widely applicable to a variety of situations both within the Naknek-Kvichak sockeye salmon setting and to other salmon runs as well. The setting, the necessary data, and the formulation of the problem really depend on the problem situation. Our purpose was to demonstrate a conceptual method and we have chosen our data and examples accordingly.

There will naturally be differences of opinion in the formulation of the model (that is, different ways of expressing the constraint equations, some of which are indicated) or the appropriate data which should be used for actual management situations. These differences can at times be easily resolved by examining the sensitivity of the model to various data or formulation modifications.

Nevertheless, we should not ignore the assumptions which are implicit in the LP procedure. These are outlined by, for example, Hillier and Lieberman (1967), and constitute three concepts that should be recognized. These involve the linearity property of the model, the problem of divisibility, and the deterministic nature of the LP approach. In addition, it is important to consider that the LP approach models only static situations. First, the linearity property asserts, for example, that the value of any term in the constraint or objective function must be directly proportional to the level of activity involved. Expressed in another way, the relation between the level of an entity and its contribution toward filling the constraint or modifying the objective function must be a straight line passing through the origin, a condition not often met in practice but frequently approximated. Furthermore, there should be no synergism among the terms of the objective or constraint functions. For example, the unit catch value on day j for the ith entity, c_{ij}, cannot be affected, a posteriori, by the unit catch value on day j-1 for the ith entity $c_{i,\ j\text{-}1}$. The problem of divisibility refers to the fact that the LP approach that we have used gives solution values which are not necessarily integers. A usual practice is to round solutions to the nearest integer value, thus avoiding the embarrassment of having, e.g., 7,012,342.631 salmon. In other applications, such as allocating 10 fishing boats, say, to perhaps three fishing grounds, the possibility of having non-integer answers may lead to erroneous conclusions and one of the integer programming techniques would then be most appropriate. Next, the deterministic nature of the LP approach is, of course, a deficiency in the probabilistic real world. The manager must realize that a full stochastic treatment of the salmon allocation as an optimization problem would most likely be a very difficult task. As alternates, an error structure could be applied to various elements in the problem, thus enabling one to explore a variety of probabilistic phenomena, or chance-constrained programming might be employed. Monte Carlo and simulation approaches might also be utilized but these are not per se optimization procedures. Finally,

the static nature of the LP approach provides a challenge to application in the sense that the unit values in the objective function, the constraints, and the right-hand sides of the constraint equations must not only be known in advance, but also must not change as a result of any of the allocations in the model.

The above assumptions can be handled in a variety of ways such as those indicated to handle problems of the deterministic nature. For example, we might, in some instances, use quadratic programming to handle the problem of non-linearity or dynamic programming or apply the outlined procedure in real time to handle the static nature of the programming problem, but unfortunately these approaches will present what can be quite complicated computational difficulties which may, in some instances, be insurmountable. It is thus clear that we have made certain approximations, trading off realism for an easily computable solution which certainly provides management guidance.

As we implied previously, we do not consider our departures from realism to seriously affect the utility of the model to provide guidance for decision making. Thus we believe that, for example, fixing the cannery capacity independent of the entities involved (or we could consider the cannery capacity to be fixed at a level which would accept a reasonable mixture of the entities) or using a simple average fecundity of the female entities to represent the average fecundity of the spawning females materially affects our conclusions. These, however, can be evaluated in direct applications by a sensitivity analysis.

Having outlined some cautions with respect to assumptions, we can now examine some of the indications provided by the various trials of the procedure. These involve the value of the fish on the dock, a reduction in processing-season length, changing value of entities during the run, and finally future data needs.

First with respect to the value of the total catch on the dock, we experimented with three value functions which set the daily value of each entity. Using the value functions to determine the value for each entity and day, and the actual distribution of the catch over the 1960 season, a total value of the catch was calculated which corresponds to the use of each of the three value functions. These values of the actual allocation of the catch were compared with the value of the optimal allocation as determined by the linear program as an indication of the value of optimally allocating the catch over the season. The increased value of the optimally allocated catch ranged from approximately $350,000 to $420,000 dependent on which value-function curve was considered. Table 3 shows these results. In the table, a fourth value function is indicated, which is simply a straight-line function such that the value of each entity remained constant through the season. Each of the other value functions was determined such that the average value of each curve was equal to the constant value for that entity for the season.

TABLE 3.—Comparison of the value of the optional allocation with the value of the actual allocation of the catch for the 1960 season.

	Value function 1[1]	Value function 2[2]	Value function 3[3]	Value function 4[4]
Optimal allocation	$13,787,050	$13,927,860	$13,792,555	$13,517,870
Actual allocation	13,378,650	13,506,250	13,439,825	13,517,890
Increased value	$ 408,400	$ 421,610	$ 352,730	$ [5]—20

[1] After day 6, the price dropped 3¢ per pound.
[2] The price was reduced by subtracting a logistic curve that reduced the price of each entity by 3¢ per pound over the season.
[3] The price was reduced by subtracting a quadratic curve that reduced the price of each entity by 3¢ per pound over the season.
[4] The price for each entity remained constant through the season (actual situation.)
[5] Difference due to rounding in the linear programming algorithm.

All three value functions had the effect of placing emphasis, in the optimal solution, on catching fish on the early days of the season. For two of the functions the value for any entity of fish on a given day is less than the value for that entity on the previous day. This is not true in the step function and thus we do not have a unique allocation, but rather a set of allocations under the high values and a set of allocations under the low values. But results are exactly the same; optimal allocations of fish are identical under the three value functions, although the total value of the catch changes somewhat, according to the exact shape of the value-function curve. Again, we emphasize that these gains from allocation can only be obtained by

knowing in advance of the run the information that we actually used in the allocation and having the ability to select the entities in the run as they are selected in the allocation.

Next, an examination of the 1960 optimal allocation reflects that this optimal allocation not only increases the value of the fish on the dock, it also shortens the length of time which a cannery needs to operate. Thus, the same amount of fish could be processed in a shorter period of time, by the same labor force, etc. In the optimal allocation for the 1960 run, all of the fish could have been processed in the first 13 days of the season, 5 days less than the actual operation. Naturally, we need to assume that a policy of catching salmon only from the early part of the run would not affect the genetic constituency of the stock. Furthermore, we must be careful here because, as we have emphasized in several places, by our LP assumptions, we cannot, a priori, let the cannery operations on day j-1, for example, affect the cannery operations on day j and we cannot at least in our formulation allow operating at peak capacity to affect quality of the fish or overtime payments since the variables are external to our model.

Another indication is that the values of fish change during the course of the season and that these values change in rather subtle ways depending upon the "rules" that we set forth (e.g., contrast Figures 8 and 9) and that in the fishery the marginal value of less valuable entities in Table 2 can be greater than the more valuable entities in Table 2. These changes in values need to be acknowledged in any management scheme.

Thus, it appears that we have the opportunity to increase the economic efficiency of some salmon runs. This is, of course, not a new concept, having been treated in some detail by, for example, Crutchfield and Pontecorvo (1969). Our approach is slightly different, however, in that we have concentrated on optimality only from the point of view of increasing the value, as we have defined it, of the fish on the dock. Any full treatment of the management problem must, of course, consider the distribution of fishing effort and its ancillary fishing and economic implications.

Now if we accept the premise that conservation is "optimum" allocation of resources in the times-space stream (*cf.* Crutchfield and Pontecorvo, 1969), and if we observe that mathematical programming provides guidance for optimal allocation, and note that LP is a special case of mathematical programming, and suggest that the kinds of information required to allocate salmon among the days of the run in an LP model are not going to be much different from the kinds of information required for more sophisticated programming procedure, then we are led to the conclusion that perhaps we have not addressed ourselves to asking, in our research, the "right questions" concerning salmon management. Following our argument, it would then be implicit that the right questions are contained in our formulation of the LP model. These answers must be feasible to obtain and they would contain either needed data or documented policies which would be reflected in the right-hand side of the constraint equations and, more importantly, provide an opportunity for enlightened dialogue. There is unfortunately a cost associated with asking right questions. This cost involves the cost of doing new work, or that which inevitably results when existing research activities are reallocated. Are these costs worth the expenditure? These, however, are the kind of questions, the answers to which can be guided by the LP problem. For the salmon management model, we impute values to units of cannery capacity, etc., but, and perhaps of equivalent importance, we impute a value, in meaningful terms, to information. Thus, for our salmon problem, we have cleverly avoided indicating how we could catch X_{ij} fish for some i,j. But it is well known that catching can be approximated because it is possible to catch salmon in traps (although this has never been done to any large extent in Bristol Bay) and, upon visual inspection, to distinguish between large and small, male and female fish, and doing this by virtue of *ceteris paribus*, the allocative process, we could add about 0.5 million dollars to the value of the salmon on the dock. This is, of course, not the full picture, because we would have to trade off the added value of salmon (it

is a common opinion that salmon caught in traps are of better condition and higher value than the salmon which are taken by gill netting, for example), the reduction in cannery days used to process the fish, the cost of building traps, and the political problems which are described in some detail in Crutchfield and Pontecorvo (1969). It would not, however, be difficult to determine the discounted present value of the various alternate procedures and thus evaluate the wisdom of engaging in any. In this evaluation, we need not be bound by what are perhaps extreme solutions such as traps, but we could examine the value of other selectivity procedures such as modifying gill net selectivity, etc. In general, then, we can evaluate the value of information by approximating that information, employing it in the model, and contrasting the change in the objective function with the objective function when the information is not in the model.

Additional information is needed on the pattern of the run. For the earlier years, this is available in Royce (1965), a publication which needs to be updated and implemented to obtain even rough estimates of the temporal movement of the fish of various entities through the fishery. This might be quite difficult to accomplish with present concepts, and the feasibility of a system which would acoustically monitor the passage of salmon through the entire river system and developing a central computer-oriented unit which would process the signals from all acoustic units and provide, in real time, through appropriate algorithms, rules for catching fish and making observations on escapement is presently being explored.

In our model, because of a lack of information, we used the total run and allocated this proportionately among the days of the fishery to determine the daily run. This emphasizes the need to have, for the purpose of management, a fairly accurate preseason guess of the total magnitude of the run and the X_{ij}'s. These guesses are already being made and the predictions need to be judged on the basis of whether the predictions do better than simply averaging the run for cycle years and simply averaging the run for noncycle years and applying these averages as predictions. The trick then may not be to estimate the average catch but rather to determine which years are cycle years.

We have included cannery capacity in a rather simple way in our model and this is a subject that also needs additional data since the cannery capacity constraint can be formulated in a variety of ways. It would be interesting to explore in a simulation setting the behavior of the slack variables in the cannery constraint. This is because it seems quite likely that there is a positive correlation between the cost of operating a cannery and the magnitude of the slack variable in the cannery constraint. If the run was constant from year to year, then it would be relatively easy to determine an optimal value for the magnitude of the slack variable in the cannery constraint. But the run varies considerably from year to year, and so in those years when the cannery constraint might be too low, we have an opportunity cost which appears as a slack variable in the dual formulation of the cannery constraint. It would seem then that the best value of the cannery constraint would be somewhere in between the capacity for a maximum run and a minimum run and that this might be investigated by employing the LP model in a simulation setting.

We have also employed egg and sex ratio constraints in our model. The egg constraints require information on fecundity and escapement. There is not much information on fecundity but this should be either easily obtainable or easily approximated. Again, the static nature of the LP problem makes it difficult to attribute a value to an egg for years in the future. This is, of course, important, emphasizing the need of thinking not, as is conventionally done, in terms of the forthcoming year, but rather in terms of, for example, a series of years maximizing (*cf.* Riffenburgh, 1969) economic benefits. In other words, the utilizers of resources may not be interested (even though they may think they are) in management on a year-to-year basis; rather, they are interested in some long-run satisfactory behavior of the time stream of economic benefits. Alternatively, though, we must be cautious of on-the-average management schemes which are typically presented in fishery appli-

cations. This is because a particular management scheme might be on-the-average quite profitable in the long run but might frequently completely bankrupt the system for the first 20 years of operation.

The problem of sex ratio is quite important because it appears that the objective function would be quite sensitive to selectively decreasing the number of males in the escapement and thus increasing the catch perhaps substantially. As indicated previously, Mathisen's study (1962) gives us some guidance on this subject and it would appear that, in some instances, the 3:1 ratio might be conservative. Furthermore, it should be mentioned that a year-to-year modification of sex ratio might be a useful cushion for approaching stability for some economic aspect of the fishery. Finally, the problem of escapement eludes us because in the wealth of literature on the subject there appears to be very little that is useful in setting the egg-minimum constraint. It is generally agreed that the stock-recruitment relation for salmon is the familiar Ricker-type curve. It is well known that the variability in these relations is quite large (in the case of the Naknek-Kvichak run, attempting to draw similarities between stock and recruitment places tremendous stresses on the imagination anyhow) and as a consequence, if the dome-shaped model holds, a minimum escapement set sufficiently, but not unreasonably high, could, on the average be reducing the return rather than increasing the return.

It might be difficult even after several years of setting the minimum escapement value at too high a level, to detect, owing to the variability in the system, the effect of this policy. If this is true, then again we are asking the wrong questions by studying the stock and recruitment model per se. We are faced with a system that is so variable, either intrinsically or in terms of measurement techniques, or both, that a large number of data points is required before we can evaluate the relation between the empirical data and the theory and then use the theory to predict. There is but one point a year and so we are asking nature to "stand still" for a large number of years. Given these observations and our past experience, we wonder whether it might not be more appropriate for management purposes to avoid looking at stock and recruitment per se, to intensify study of the physiology and behavior of very young stages of fish, and thus examine fundamental problems of cause and effect, vis-á-vis the variables that influence the magnitude of egg production and survival of these eggs and larvae or other young stages through the first several months of their life. And finally, in the meantime, would it be more appropriate to consider measuring stock and recruitment in terms of transition probabilities which might be estimated by computing the median stock and the median recruitment? Stock sizes which are below the median would be poor, those which are above, good, and similarly with recruitment. The empirical data could then be used to estimate probabilities of good-good, good-poor, poor-good, and poor-poor transitions. We need not in this procedure be restricted to medians, but could in fact use any fractile, and in fact we need not be restrained by fractiles because we might want to place the dividing line at some "optimal value" and explore the consequences.

In conclusion, then, we have formulated a LP model for salmon runs and have shown how it might be related to the Naknek-Kvichak run. We see in this relationship that, given information on the structure of the run, we can both increase the value of the fish on the dock and at the same time reduce processing time. Whether it is worth obtaining the information in terms of the indicated data and the ability to select fish from the run to approach this allocation and whether decreased processing time is, in fact, a saving, are questions that must be answered by the processing industry in light of the increased value of salmon on the dock. If our estimate of increased value is approximately correct, we can see that allocation can add an interesting value to the catch, but far greater additions could come from reducing the escapement, if this is possible, and alleviating the open-access related problems. Perhaps the most interesting feature of the model is the richness of interpretations that LP affords in the salmon situation and the nature of questions and data needs raised by the model. Finally, we emphasize that, as Hillier and Lieberman (1967) note,

"A practical problem which completely satisfies all of the assumptions of LP is very rare indeed. However, the LP model is often the most accurate representation of the problem, which will yield a reasonable recommendation for action before implementation is required."

ACKNOWLEDGMENTS

Much of the data used in this paper was unavailable in the literature. We obtained unpublished information on cannery operations from several members of the salmon industry. Bruce B. Bare was kind enough to advise us on several aspects of the linear-programming technique. We also thank Donald E. Rogers for supplying us with unpublished biological data and considerable advice. We appreciate the critical reviews which were given by Robert L. Burgner, Gardner M. Brown, Douglas G. Chapman, and Allan C. Hartt, all of the University of Washington, and we appreciate as well the various suggestions made by anonymous referees.

LITERATURE CITED

Burgner, Robert L., Charles J. DiCostanzo, Robert J. Ellis, George Y. Harry, Jr., Wilbur L. Hartman, Orra E. Kerns, Jr., Ole A. Mathisen, and William F. Royce.
1969. Biological studies and estimates of optimum escapements of sockeye salmon in the major river systems in southwestern Alaska. U.S. Fish Wildl. Serv. Bull. 67(2): 405-459.

Crutchfield, James A., and Giulio Pontecorvo.
1969. Pacific salmon fisheries: A study of irrational conservation. Johns Hopkins Press, Baltimore, Md., 220 p.

Gass, Saul I.
1964. Linear programming. McGraw Hill, Inc., New York, N.Y., 280 p.

Hillier, F. S., and G. J. Lieberman.
1967. Introduction to operations research. Holden-Day, Inc., San Francisco, Calif., 639 p.

Mathisen, Ole A.
1962. The effect of altered sex ratios on the spawning of red salmon. *In* Ted Swei-yen Koo (ed.), Studies of Alaska red salmon, p. 137-245. University of Washington Press, Seattle, Wash.
1969. Growth of sockeye salmon in relation to abundance in the Kvichak district, Bristol Bay, Alaska. Fiskeridir. Skr. Ser. Havunders. 15(3): 172-185.

Mathews, Stephen Barstow.
1966. The economic consequence of forecasting sockeye salmon (*Oncorhynchus nerka* Walbaum) runs to Bristol Bay, Alaska: A computer simulation study of the potential benefits to a salmon canning industry from accurate forecasts of the runs. Ph.D. Thesis, University of Washington, Seattle, Wash., 238 p.

Riffenburgh, Robert H.
1969. Stochastic model of interpopulation dynamics in marine ecology. J. Fish. Res. Bd. Can. 26(11): 2843-2880.

Royce, William 6.
1965. Almanac of Bristol Bay sockeye salmon. Univ. Wash., Fish. Res. Inst., Circ. 234, 48 p.

APPENDIX TABLE 1.—Constants used in value-function equations for each entity and day of the 1960 run.

		Function 1[1]	Function 2[2]	Function 3[3]
Entity 1	IP_1	1.382	1.365	1.331
	b_1	.153	.153	.000417
Entity 2	IP_2	1.998	1.974	1.925
	b_2	.222	.222	.000583
Entity 3	IP_3	1.470	1.455	1.425
	b_3	.135	.135	.000472
Entity 4	IP_4	1.964	1.944	1.903
	b_4	.186	.186	.000694

[1] For entity i on day j,
Value $_{i,j} = IP_i$, for $j < 6$; Value $_{i,j} = IP_i$ — .03X (weight of entity i in pounds), for $j > 6$.

[2] For entity i on day j,
$$\text{Value}_{i,j} = IP_i - \frac{b_i}{1+e^{-(4.5+.5j)}}$$

[3] For entity i on day j,
Value $_{i,j} = IP_i - b_i X^{j2}$

APPENDIX TABLE 2.—Total run, total catch, and value functions for each entity and day of the 1960 season.

Entity	Day	Total run	Total catch	Value function 1[1]	Value function 2[2]	Value function 3[3]	Entity	Day	Total run	Total catch	Value function 1[1]	Value function 2[2]	Value function 3[3]
1	1	280,351	119,149	1.382	1.362	1.331	3	1	211,080	53,192	1.470	1.453	1.425
	2	368,062	156,426	1.382	1.361	1.329		2	277,120	69,834	1.470	1.451	1.423
	3	475,118	201,925	1.382	1.358	1.327		3	357,724	90,146	1.470	1.449	1.421
	4	600,110	255,046	1.382	1.353	1.323		4	451,832	113,861	1.470	1.445	1.418
	5	737,489	313,432	1.382	1.347	1.319		5	555,267	139,927	1.470	1.439	1.415
	6	876,389	372,465	1.382	1.337	1.314		6	659,846	166,281	1.470	1.430	1.410
	7	1,000,833	425,354	1.229	1.324	1.308		7	753,542	189,892	1.335	1.419	1.405
	8	1,092,325	464,238	1.229	1.307	1.301		8	822,427	207,252	1.335	1.404	1.398
	9	1,134,780	482,281	1.229	1.288	1.293		9	854,393	215,307	1.335	1.387	1.391
	10	1,120,032	476,014	1.229	1.270	1.284		10	843,289	212,488	1.335	1.371	1.383
	11	1,050,967	446,661	1.229	1.253	1.274		11	791,289	199,404	1.335	1.356	1.375
	12	940,395	399,668	1.229	1.240	1.264		12	708,038	178,426	1.335	1.345	1.365
	13	806,344	342,696	1.229	1.230	1.251		13	607,110	152,992	1.335	1.336	1.355
	14	666,514	283,268	1.229	1.224	1.238		14	501,829	126,460	1.335	1.330	1.343
	15	534,438	227,136	1.229	1.219	1.225		15	402,387	101,401	1.335	1.326	1.331
	16	418,185	177,729	1.229	1.216	1.210		16	314,858	79,344	1.335	1.324	1.318
	17	321,003	136,426	1.229	1.215	1.195		17	241,688	60,905	1.335	1.322	1.304
	18	242,797	103,188	1.229	1.214	1.178		18	182,805	46,066	1.335	1.321	1.290
2	1	9,590	5,427	1.998	1.970	1.924	4	1	24,985	17,289	1.964	1.941	1.902
	2	12,590	7,126	1.998	1.967	1.922		2	32,803	22,700	1.964	1.939	1.901
	3	16,252	9,199	1.998	1.963	1.919		3	42,344	29,302	1.964	1.935	1.898
	4	20,528	11,618	1.998	1.957	1.914		4	53,484	37,010	1.964	1.930	1.894
	5	25,227	14,278	1.998	1.948	1.908		5	65,727	45,483	1.964	1.922	1.888
	6	29,978	16,967	1.998	1.934	1.900		6	78,106	54,050	1.964	1.910	1.882
	7	34,235	19,377	1.776	1.914	1.891		7	89,197	61,724	1.778	1.894	1.874
	8	37,365	21,149	1.776	1.890	1.881		8	97,351	67,367	1.778	1.874	1.866
	9	38,817	21,970	1.776	1.863	1.869		9	101,135	69,985	1.778	1.851	1.856
	10	38,313	21,968	1.776	1.836	1.856		10	99,820	69,075	1.778	1.828	1.845
	11	35,950	20,347	1.776	1.812	1.841		11	93,665	64,816	1.778	1.808	1.832
	12	32,168	18,207	1.776	1.792	1.825		12	83,811	57,997	1.778	1.792	1.819
	13	27,582	14,479	1.776	1.778	1.808		13	71,864	49,730	1.778	1.780	1.804
	14	22,800	12,905	1.776	1.769	1.789		14	59,402	41,106	1.778	1.772	1.789
	15	18,281	10,347	1.776	1.763	1.769		15	47,631	32,960	1.778	1.767	1.772
	16	14,305	8,096	1.776	1.759	1.747		16	37,270	25,790	1.778	1.763	1.754
	17	10,980	6,215	1.776	1.756	1.724		17	28,609	19,797	1.778	1.761	1.735
	18	8,305	4,700	1.776	1.754	1.700		18	21,639	14,974	1.778	1.760	1.714

[1] After day 6, the price dropped 3¢ per pound.
[2] The price was reduced by subtracting a logistic curve that reduced the price of each entity by 3¢ per pound over the season.
[3] The price was reduced by subtracting a quadratic curve that reduced the price of each entity by 3¢ per pound over the season.

CHEMICAL AND NUTRITIONAL CHARACTERISTICS OF FISH PROTEIN CONCENTRATE PROCESSED FROM HEATED WHOLE RED HAKE, *Urophycis chuss*

DAVID L. DUBROW AND BRUCE R. STILLINGS[1]

ABSTRACT

This study was to determine whether cooking lean, whole fish before they are extracted by solvent affects the chemical and nutritional characteristics of the resulting fish protein concentrate. When red hake were heated at 100° and 109° C for as long as 80 min, the chemical and nutritional properties of the fish protein concentrate were not adversely affected significantly. The nutritional quality was slightly lower, however, in fish protein concentrate produced from red hake that were heated at 121° C for 10 to 80 min.

Fish protein concentrate (FPC) contains protein that is high in quality. It therefore can be used to supplement diets that contain inadequate amounts of high-quality protein.

Fish protein concentrate is prepared by removing most of the lipids and water from whole fish. Several methods for preparing FPC have been investigated. They can be classified as chemical, biological, and physical. Most investigators have used chemical methods in which solvents extract the lipids and water from whole fish.

In the United States, two processes for making FPC have been approved by the Food and Drug Administration. Both of these are chemical processes in which solvents are used. In the overall program of the National Marine Fisheries Service National Center for Fish Protein Concentrate, various approaches to processing are being investigated. One such approach is cooking and pressing fish prior to solvent extraction. This procedure would tend to reduce the volume of solvent required for extraction, inasmuch as water and lipids would be expressed during the pressing stage.

Raw fish are difficult to press because of their physical consistency. The processor can overcome this problem by cooking the fish before pressing them. If he subjects the fish to a high temperature for a long time, however, undesirable chemical reactions may occur that decrease the quality of the protein.

The purpose of this study therefore was to find whether or not the chemical composition and nutritional quality of fish protein concentrate are altered when the FPC is produced by solvent extraction of fish that have been cooked at different temperatures for varying periods of time.

CHEMICAL COMPOSITION

Reported here are both the proximate composition and amino acid composition of the FPC produced from cooked fish.

PROXIMATE COMPOSITION

We used red hake, *Urophycis chuss*, which are lean fish. They were caught off the coast of New England in the area of Block Island, situated south southwest of Point Judith, R.I. The hake were iced on board the vessel and were then frozen in 25-lb. wax laminated cartons at the dock. The hake were kept frozen while being shipped to the National Marine Fisheries Service National Center for Fish Protein Concentrate in College Park, Md. The shipment contained about 96 cartons. From these 96 boxes, 15 cartons (375 lb.) were picked at random for the investigation and were stored

[1] National Marine Fisheries Service National Center for Fish Protein Concentrate, College Park, Md. 20740.

Manuscript received August 1970
FISHERY BULLETIN: VOL. 69, NO. 1, 1971.

at —20° C (The other cartons were used in another experiment.) The hake were used within 1 month after storage.

About 17 to 18 hr before studying each processing variable, we placed one carton of fish in a refrigerated room at a temperature of 5° to 6° C. This treatment allowed the fish to thaw sufficiently so that they could be handled individually. The fish were ground through a Hobart meat grinder,[2] which was equipped with an end plate containing holes that were one-quarter inch in diameter. After the hake were ground, they were thoroughly mixed, and a sample that weighed 20 lb was removed. The sample was divided into three equal portions, and each portion was placed in a 2-inch-deep tray lined with aluminum foil. (This procedure was used in order to permit existing equipment to be used.)

The trays were placed in an autoclave and were heated at 100°, 109°, or 121° C for 10, 20, 40, or 80 min. Thermocouples were used to measure the temperature of the samples. After being heated, the trays were removed from the autoclave, were covered with aluminum foil, and were cooled in a refrigerated room at 5° to 6° C. A control sample was also prepared, which consisted of raw, unheated ground hake.

The entire contents of the trays were mixed with solvent at a 2:1 (w/w) ratio of solvent to solid. The samples were extracted by the "cross-current" batch-extraction procedure described by Brown and Miller (1969). The solvent used for extraction was 91%, by volume, isopropyl alcohol.

The extracted and dried samples of FPC were ground in a Rietz Disintegrator.

The samples were analyzed for crude protein, volatiles, and ash by the methods described by Horwitz (1965). Lipids were determined by the method of Smith, Ambrose, and Knobl (1964).

Table 1 shows the concentrations of crude protein, ash, and lipids found.

The concentration of crude protein in the samples that were heated was slightly lower than in the sample that was not heated. The concentration of crude protein, however, was not significantly affected by the temperature at which the samples were heated. Also, the time of heating did not significantly affect the concentration of crude protein in the samples, except for the 20-min treatment. The samples that were heated for 20 min had a slightly lower concentration of crude protein than did those that were heated for the other intervals of time.

TABLE 1.—Proximate composition, expressed on a moisture-free basis, of samples of FPC prepared from hake that were heated for varying times and temperatures before being extracted with solvent.

Sample	Crude protein	Ash	Lipid
	%	%	%
Nonheated control	88.7	13.8	0.16
Heated samples:			
100° C for:			
10 min	86.0	15.3	0.16
20 min	85.3	15.4	0.16
40 min	86.3	15.0	0.20
80 min	85.9	15.5	0.15
Mean	85.9	15.3	0.17
109° C for:			
10 min	87.5	14.4	0.12
20 min	85.6	15.8	0.12
40 min	86.8	15.7	0.21
80 min	87.4	13.8	0.15
Mean	86.8	14.9	0.15
121° C for:			
10 min	87.3	13.6	0.12
20 min	85.9	15.2	0.14
40 min	86.5	13.7	0.16
80 min	86.8	14.3	0.16
Mean	86.6	14.2	0.14

The concentration of ash was slightly higher in the samples that were heated than in the sample that was not heated. The concentration of ash in the heated samples was not affected by either the temperature of heating or the length of time of heating.

The concentration of lipid in the samples was somewhat variable, but it was not significantly affected by the treatments.

AMINO ACID COMPOSITION

Essential amino acids, except for tryptophan, were determined with an automatic amino acid analyzer by the method described by Moore, Spackman, and Stein (1958). Tryptophan was determined chemically by the method of Spies and Chambers (1949). Cystine was determined

[2] The use of trade names is merely to facilitate descriptions; no endorsement is implied.

microbiologically by the method of Henderson and Snell (1948). Available lysine was determined by the method described by Carpenter (1960).

We found only slight changes in the concentrations of amino acids in the samples (table 2). The treatments that we used did not consistently affect the concentrations of amino acids, except for cystine and available lysine. The concentration of cystine was reduced in the sample heated at 121° C for 80 min. The concentrations of available lysine were slightly lower in the samples heated at 100° and 109° C for 20 min. The reason for these decreases is not apparent to us.

Evans and McGinnis (1948) previously reported that cystine was reduced when soybeans were autoclaved at 130° C for 60 min.

NUTRITIONAL QUALITY

The nutritional quality of the samples was determined in a feeding study using rats. Diets were prepared that contained 10% protein from the heated samples, the nonheated sample, or casein. The diet that contained the nonheated sample served as a control, and the one that contained casein served as a reference standard. The composition of the basal diet was described earlier by Stillings, Hammerle, and Snyder (1969).

Male weanling rats of the Carworth Farms CFE strain were received when they were 22 days old. The rats were housed individually in cages with screen bottoms and were kept in an air-conditioned room maintained at about 23° C. During the first 2 days, the rats were fed a basal diet containing 15% casein. They were then allotted to groups on the basis of weight, and the groups were randomly assigned to different diets. Each group contained 10 rats, and the rats were offered feed and water *ad libitum* for 4 weeks.

The amount of feed consumed was recorded three times each week, and the gains in weight were determined once each week. At the end of the experiment, the protein efficiency ratio was determined by dividing the gain in weight by the weight of protein consumed.

The data were analyzed statistically. Differences between means were determined by Tukey's procedure as described by Steel and Torrie (1960: 109).

Table 3 shows the data on the nutritive quality of the FPC samples. Based on the gain in weight, intakes of feed, and protein efficiency ratios, the quality of the samples that were heated at 100° and 109° C was not significantly different from the quality of the control, which was not heated. Samples that were heated at 121° C, however, had a lower quality than the control sample. In general, the quality of the samples heated at 100° and 109° C was equal to that of casein or was slightly higher than

TABLE 2.—Amino acid composition of FPC samples prepared from hake that were heated for varying times and temperatures before being extracted with solvent.

Amino acid	Concentration of amino acid in:											
	Unheated control sample	Samples heated at:										
		100° C for:				109° C for:				121° C for:			
		10 min.	20 min.	40 min.	80 min.	10 min.	20 min.	40 min.	80 min.	10 min.	20 min.	40 min.	80 min.
	Grams per 16 grams of nitrogen												
Arginine	6.2	6.7	6.4	6.8	6.4	5.7	7.0	6.1	6.4	6.9	6.1	6.6	6.3
Histidine	1.8	2.0	1.9	1.9	1.8	1.7	1.9	1.7	1.8	2.1	1.9	1.8	2.0
Isoleucine	4.5	4.3	4.4	4.5	4.3	4.3	4.6	4.5	4.5	4.9	4.6	4.4	4.8
Leucine	7.4	7.2	6.9	7.1	6.9	7.0	7.5	7.0	7.2	8.0	7.2	7.3	7.6
Lysine	7.7	8.3	7.8	8.0	7.4	7.1	7.7	7.1	7.5	8.4	7.5	7.9	7.6
Methionine	3.2	3.1	3.1	3.1	3.0	3.0	3.0	3.1	3.0	3.6	3.1	3.1	3.4
Phenylalanine	4.1	4.1	4.0	4.1	4.0	4.0	4.2	4.1	4.1	4.5	4.1	4.2	4.3
Threonine	4.3	4.2	4.1	4.2	4.0	4.0	4.4	4.2	4.0	4.6	4.1	4.2	4.4
Tryptophan	1.0	1.2	1.2	1.0	1.3	1.2	1.1	1.1	1.2	1.1	1.2	1.3	1.2
Valine	5.1	4.9	5.0	5.0	5.1	4.8	5.2	4.6	5.0	5.5	5.0	5.0	5.3
Cystine	0.9	1.2	1.2	1.2	0.9	1.1	1.1	1.1	1.1	1.1	1.1	--	0.7
Available lysine	7.9	7.8	6.9	7.2	7.9	7.7	6.9	7.2	7.6	7.8	7.1	7.2	7.6

TABLE 3.—Weight gain, feed intake, and protein efficiency ratio of groups of 10 rats fed diets of FPC samples prepared from red hake that were heated for varying times and temperatures before being extracted with solvent.

Sample	Average daily weight gain	Average daily feed intake	Protein efficiency ratio
	Grams	*Grams*	
Nonheated control	4.85	13.8	3.37
Heated samples:			
100° C for:			
10 min	4.96	14.0	3.41
20 min	4.37	13.0	3.25
40 min	4.50	13.1	3.37
80 min	4.29	13.3	3.16
Mean	4.53	13.4	3.30
109° C for:			
10 min	4.37	12.7	3.35
20 min	4.31	13.1	3.11
40 min	4.45	13.4	3.20
80 min	4.20	12.6	3.28
Mean	4.34	13.0	3.24
121° C for:			
10 min	3.21	10.6	3.01
20 min	4.01	12.2	3.13
40 min	3.52	11.1	3.10
80 min	3.20	10.3	3.02
Mean	3.49	11.0	3.07
Casein	3.85	12.0	3.18
Tukey's W ($P<0.05$)	0.81	2.0	0.26

that of casein. When the temperature was increased to 121° C, the quality of the samples was slightly lower than that of casein but not significantly so. At each temperature, the temperature at which the samples were heated had a more significant effect on the quality of the samples than did the length of time of heating.

SUMMARY AND CONCLUSIONS

We conducted a study to determine the chemical composition and nutritional quality of FPC produced from fish that are heated before they are extracted with solvent. Red hake, which are lean fish, were heated at 100° C for 10, 20, 40, or 80 min. Other samples were heated for these same lengths of time at 109° or 121° C. The samples were then extracted with isopropyl alcohol. The FPC produced from the samples of hake that were heated contained slightly less crude protein and more ash than did the FPC produced from the samples that were not heated. The amino acid composition of samples that had been heated did not differ markedly from the composition of those that were not heated. The nutritive quality of the samples that were heated at 100° and 109° C was not significantly affected. Samples heated at 121° C, however, were lower in quality than was the control sample.

We conclude that red hake can be heated at temperatures of 100° and 109° C for as long as 80 min before being extracted by solvent without the quality of the protein being affected significantly.

LITERATURE CITED

BROWN, NORMAN L., AND HARRY MILLER, JR.
1969. Experimental production of fish protein concentrate (FPC) from Mediterranean sardines. Commer. Fish. Rev. 31(10): 30-33.

CARPENTER, K. J.
1960. The estimation of available lysine in animal-protein foods. Biochem. J. 77(3): 604-610.

EVANS, ROBERT JOHN, AND JAMES MCGINNIS.
1948. Cystine and methionine metabolism by chicks receiving raw or autoclaved soybean oil meal. J. Nutr. 35(4): 477-488.

HENDERSON, L. M., AND ESMOND E. SNELL.
1948. A uniform medium for determination of amino acids with various microorganisms. J. Biol. Chem. 172(1): 15-29.

HORWITZ, WILLIAM (chairman and editor).
1965. Official methods of analysis of the Association of Official Agricultural Chemists. 10th ed. Association of Official Agricultural Chemists, Washington, D.C., xx + 957 pp. Sections 22.003, 22.010, and 22.011.

MOORE, STANFORD, DARREL H. SPACKMAN, AND WILLIAM H. STEIN.
1958. Chromatography of amino acids on sulfonated polystyrene resins. Anal. Chem. 30(7): 1185-1190.

SMITH, PRESTON, JR., MARY E. AMBROSE, AND GEORGE N. KNOBL, JR.
1964. Improved rapid method for determining total lipids in fish meal. Commer. Fish. Rev. 26(7): 1-5.

SPIES, JOSEPH R., AND DORRIS C. CHAMBERS.
1949. Chemical determination of tryptophan in proteins. Anal. Chem. 21(10): 1249-1266.

STEEL, ROBERT G. D., AND JAMES H. TORRIE.
1960. Principles and procedures of statistics with special reference to the biological sciences. McGraw-Hill Book Company, Inc., New York, xvi + 481 pp.

STILLINGS, B. R., O. A. HAMMERLE, AND D. G. SNYDER.
1969. Sequence of limiting amino acids in fish protein concentrate produced by isopropyl alcohol extraction of red hake (*Urophycis chuss*). J. Nutr. 97(1): 70-78.

EFFECT OF ICE STORAGE ON THE CHEMICAL AND NUTRITIVE PROPERTIES OF SOLVENT-EXTRACTED WHOLE FISH—RED HAKE, *Urophycis chuss*

David L. Dubrow, Norman L. Brown, E. R. Pariser, Harry Miller, Jr., V. D. Sidwell, and Mary E. Ambrose[1]

ABSTRACT

Because red hake that are to be used in the future production of fish protein concentrate will be caught in quantity, the preservation of the hake during periods of glut will present a problem that possibly can be solved by storage of the hake in ice.

In our study of this problem, whole red hake were held in ice for 2, 6, 8, and 11 days. Organoleptic tests on the fresh fish showed that they were edible on the 8th day but were not edible on the 11th day.

Samples of fish were removed during each period of storage and were processed (1) by freeze-drying to produce a reference sample (2) by solvent extraction with isopropyl alcohol to produce a fish protein concentrate. Proximate composition, amino acid composition, and nutritive quality were determined comparatively on both of these two kinds of processed samples.

From the data obtained, we concluded that red hake stored in ice for 8 days are suitable for use in the production of fish protein concentrate and that they would be suitable for this use up to the point of spoilage of the fish, which occurs sometime between 8 and 11 days.

In the period between the capture and processing of fish that are to be used in products for human consumption, they must be preserved in a manner that maintains their food-grade quality. This requirement applies to the production of fish protein concentrate (FPC) as well as to that of more common fish products.

The preservation of fish is a problem not only aboard the harvesting vessel but at the shore processing plant as well. The problem ashore becomes especially important during periods of glut when the fresh fish must be held several days before being processed.

In the manufacture of FPC by the method we use, oil and moisture are removed from the fish with isopropyl alcohol. We therefore investigated the possibility of holding fish in this solvent (Dubrow and Hammerle, 1969). We found the method to be entirely suitable for periods of holding up to 11 days.

Although storage in isopropyl alcohol was satisfactory, more conventional means of holding the fish, such as storing them in ice, are likely to be used in commercial operations. During the time fish are held in ice, however, considerable change may occur in the components of the fish tissue. Endogenous and bacterial enzymes may break down protein into water-soluble and volatile components, causing off-flavors and odors in the fish. In addition, the highly unsaturated lipids of the fish may oxidize rapidly, causing the fish to become rancid.

While these changes are taking place in iced fish, the water from the melting ice is leaching out some of the compounds that are forming. Furthermore, the subsequent extraction with alcohol during the production of FPC, if adequate, removes most of the undesirable compounds that were not leached out by the melt water.

Just what effect the enzymatic and oxidative changes have on the various components of the tissues as well as on the nutritive quality of the protein in the finally processed FPC is not known. Accordingly, solubilization of the components of the fish tissues could alter the composition of the finally processed FPC. We should

[1] National Marine Fisheries Service National Center for Fish Protein Concentrate, College Park, Md. 20740.

Manuscript received August 1970.

know, of course, what occurs, because FPC is of value solely as a protein supplement of high quality.

The aim of this study therefore was to determine the effect that storage of food-grade fish in ice has on the chemical composition of the components of the tissue and on the nutritive quality of the protein. We accomplished this aim by comparing FPC made from samples of the ice-stored fish with reference samples made by freeze-drying samples of the fish. We used freeze-drying because we believe that this method of production results in minimum alteration in the samples during drying.

CHEMICAL COMPOSITION

Both the proximate composition and the amino acid composition of the samples were determined.

PROXIMATE COMPOSITION

As indicated earlier, we used standard reference samples produced under ideal conditions, as a basis on which to evaluate our samples of FPC.

Standard Reference Sample

About 600 lb of red hake were caught on January 6, 1965, in 25 to 26 fathoms of water off the coast of Rhode Island. The fish were divided randomly into lots of 100 lb each, were iced immediately, and then were taken to the Bureau of Commercial Fisheries (BCF) (now National Marine Fisheries Service) Technological Laboratory at Gloucester, Mass., where they were held in ice.

During the next 11 days, each lot of fish was inspected periodically for freshness by experienced BCF fish inspectors at Gloucester. The factors they considered were (1) damage to the fish, (2) conditions of the skin, eyes, and gills, and (3) texture, odor, and flavor of cooked samples. A numerical score ranging from one to four was used to rate fish of varying quality for each of the factors. Fish of perfect or nearly perfect quality were assigned a value of 1, whereas those at the limit of acceptability or beyond the limit were assigned a value of 4.

Table 1 shows the data on the subjective evaluation of the raw fish. The samples of fish tested after storage for 11 days in ice were judged to be at the limit of acceptability. The fish that had been stored in ice for 8 days were of acceptable quality and were considered to be of food grade.

TABLE 1.—Freshness evaluations of raw red hake stored in ice for periods up to 11 days.
[Each sample had 50 fish.]

Storage time	Average subjective evaluations of:						
	Damage	Skin	Eyes	Gills	Texture	Odor	Flavor
Days							
2	1.00	1.00	1.02	1.40	1.50	1.08	1.0
6	2.26	2.22	2.04	2.32	2.60	2.38	2.0
8	2.44	2.50	3.00	2.92	3.18	3.10	2.5
11	3.10	4.00	3.86	3.92	3.98	4.00	--

Fish of perfect or nearly perfect quality were assigned a value of 1; those of unacceptable quality were assigned a value of 4.

After the iced fish had been inspected for quality, they were shipped in ice to College Park, Md. Each box of fish, upon receipt at College Park, was divided into two groups and were processed immediately—one into a standard reference sample and the other into FPC.

One portion of 20 lb was selected at random from the group of fish to be used as a standard reference sample. The standard reference sample was prepared by freezing the fish in liquid nitrogen and grinding the whole fish through a Rietz Disintegrator[2] under a stream of liquid nitrogen, and then freeze-drying the liquid-nitrogen slurry of ground fish. The freeze-drying step was carried out under a pressure of 500μ of mercury and at a platen temperature of 40° C. The dried samples were then removed from the freeze dryer in an atmosphere of nitrogen and were sealed in containers. The containers were maintained at —40° C until the samples were needed.

The freeze-dried samples were analyzed for crude protein, ash, and volatiles in accordance with standard procedures (Horwitz, 1965). Total lipids were determined by the method of Smith, Ambrose, and Knobl (1964).

Table 2 shows the proximate composition of

[2] The use of trade names is merely to facilitate description; no endorsement of products is implied.

TABLE 2.—Proximate composition of freeze-dried, ground whole hake (standard reference samples) stored in ice for periods up to 11 days.

Storage time	Volatiles	Lipids[1]	Ash[1]	Crude protein[2]
Days	*Wt. %*	*Wt. %*	*Wt. %*	*Wt. %*
2	3.80	15.30	13.44	74.47
6	2.49	14.06	12.84	77.34
8	2.46	14.36	12.43	77.38
11	4.70	15.07	12.49	77.01

[1] The data on lipids, ash, and protein were based on the dry weight of sample.
[2] Crude protein was calculated as N X 6.25.

the various samples of freeze-dried whole fish. Data are presented on a dry-weight basis to reveal possible losses during storage.

The concentration of lipid varied between 14 and 15%; that of ash, between 12 and 13%. The data indicate that the nitrogen fraction did not change greatly. The crude protein remained relatively constant at about 77% (on a dry-weight basis) except on the second day of sampling. This deviation on the second day was probably the result of a sampling error. Analyses for nonprotein nitrogen would have been helpful for interpretive purposes. Unfortunately, they were not made. Dassow[3] has reported that the nonprotein nitrogen fraction of whole Pacific hake stored in ice did not change significantly over a period of 11 days.

Fish Protein Concentrate

From the remaining portion of each lot of fish, 20 lb were selected at random and were extracted with isopropyl alcohol according to established procedures (Brown and Miller, 1969). In brief, the fish were ground through a Hobart meat grinder, were slurried with 15 liters of 91% (v/v) isopropyl alcohol for 30 min, and were centrifuged. The centrifuged solids were then extracted continuously with hot isopropyl alcohol at 60° to 70° C and at a rate of flow of 0.2 gal per minute. After 2 hr the solids were removed by centrifugation and were desolventized under vacuum at 60° C.

[3] Dassow, John A. 1966. Statement of project accomplishment, Utilization of fishery resources program. *In* Quarterly progress report of the BCF Technological Laboratory, Seattle, Wash., July 1 - September 30, 1966. Unpublished report, 6 p.

This method of processing was not intended to be representative of commercial methods. It was used in our laboratory at that time solely as an experimental technique to evaluate selected variables in the preparation of FPC by solvent extraction. It has since been replaced by a several-stage countercurrent extraction system, which is both much more economical in the volume of solvent needed and is more representative of commercial processing methods. A comparison of FPC made by each system has shown no significant differences, however, either in chemical composition or in nutritive value.

The proximate composition was determined by the same method used with the freeze-dried fish.

Table 3 lists the proximate compositions of the FPC's prepared from the fish stored in ice for various periods. The concentrations of lipids and volatiles remained essentially unaffected by storage. The concentration of ash increased, however, and that of protein (that is, of nitrogen) decreased. The major change occurred after the 8th day of storage. Because the concentration of protein in the standard reference samples did not drop in the same manner as the concentration of protein did in the FPC's, the loss of protein could not have occurred during storage but must have occurred during processing. This conclusion could be accounted for by the formation, during storage, of soluble nitrogenous products resulting from enzymatic breakdown or bacterial breakdown, or from both, that were not leached out of the fish during storage but that were subsequently leached out during the extraction process used in making the FPC. This conclusion was further support-

TABLE 3.—Proximate composition of FPC prepared from raw fish stored in ice for periods up to 11 days.

Storage time	Volatiles	Lipids[1]	Ash[1]	Crude protein[2]
Days	*Wt. %*	*Wt. %*	*Wt. %*	*Wt. %*
2	4.25	0.18	12.30	89.70
6	5.10	0.13	12.44	89.65
8	5.12	0.10	13.19	89.30
11	4.10	0.21	16.04	86.94

[1] The data on lipids, ash, and protein were based on the dry weight of sample.
[2] Crude protein was calculated as N X 6.25.

ed by the observed decrease in yield after processing—namely, 12.0 percent of 2-day-old fish to 10.0 percent of 8-day-old fish.

Storage of whole red hake in ice up to 11 days did not influence the extractability of the lipids. A slight loss of nitrogen occurred, however, during the processing of whole fish stored for 11 days as compared with fish stored for shorter periods.

AMINO ACID COMPOSITION

Standard Reference Sample

Amino acids were determined by the method of Spackman, Stein, and Moore (1958).

Table 4 shows that the recovery of amino acids was relatively constant at about 92% of the protein. The essential amino acids for which analyses were made ranged between 45.5 and 46.3% of the total. No major change in the pattern of any one particular amino acid resulted from storage.

In general, this finding agrees with those by Cohen and Peters (1963) on whiting, *Merluccius bilinearis*, that were stored in ice. These authors reported, however, that methionine decreased after the 13th day with a subsequent increase in methionine sulfoxide. We do not know whether this compound was present in the hake that we studied.

Fish Protein Concentrate

The same methods were used as with the standard reference sample. That is, the amino acids were determined by the method of Spackman, Stein, and Moore (1958).

Table 5 shows the concentration of amino acids in the FPC's processed from the fish held in ice. The data indicate that about 100% of the amino acids were recovered.

The essential amino acids constituted 47% of the total amino acids in the FPC made from fish stored 2 days, but the concentration of these amino acids dropped to 43% after the fish had been stored 11 days. Individual amino acids decreased in concentration. Of these amino acids, leucine and isoleucine decreased slightly, whereas lysine and histidine decreased markedly after the 8th day of storage. The total concentration of lysine was about 11% less in the FPC made after the fish had been stored for 11 days than in the FPC produced after they had been stored for 2 days. The concentration of histidine

TABLE 4.—Amino acid composition of raw freeze-dried whole ground fish. The samples were prepared after fish were held in ice for periods up to 11 days.

Amino acid	Concentration of the given amino acid in the Standard Reference Samples after they were held:			
	2 days	6 days	8 days	11 days
	— — — *Percent of the protein (N X 6.25)* — — —			
Lysine	7.63	7.44	7.72	7.56
Histidine	1.92	1.77	1.92	1.76
Ammonia	1.68	1.57	1.58	1.59
Arginine	5.96	5.82	6.05	5.76
Aspartic acid	9.50	9.41	9.45	9.53
Threonine	4.07	4.16	4.08	4.14
Serine	4.08	4.22	4.11	4.11
Glutamic acid	14.05	14.32	14.27	14.23
Proline	4.57	4.79	4.69	4.76
Glycine	7.70	8.23	7.68	7.52
Alanine	6.50	6.56	6.36	6.41
Valine	4.88	4.78	4.63	4.98
Methionine	3.02	3.00	2.91	3.05
Isoleucine	4.21	4.17	4.13	4.32
Leucine	7.07	7.03	7.06	7.21
Tyrosine	3.01	2.90	2.88	2.99
Phenylalanine	3.82	3.98	3.98	3.94
Total amino acid recovery	91.99	92.58	91.92	92.27
Percent essential amino acids	46.29	45.51	46.21	46.30

TABLE 5.—Amino acid composition of FPC prepared from raw fish held in ice for periods up to 11 days.

Amino acid	Concentration of the given amino acid in the samples extracted after they were held for:			
	2 days	6 days	8 days	11 days
	— — — *Percent of the protein (N X 6.25)* — — —			
Lysine	8.67	8.14	8.38	7.72
Histidine	2.06	1.88	2.00	1.74
Ammonia	1.47	1.57	1.39	1.44
Arginine	7.12	6.98	7.24	6.92
Aspartic acid	10.36	10.36	10.17	10.00
Threonine	4.45	4.48	4.51	4.44
Serine	4.60	4.59	4.70	4.75
Glutamic acid	15.47	15.57	15.34	15.27
Proline	5.01	5.64	5.59	6.47
Glycine	8.04	9.20	9.12	10.23
Alanine	6.78	7.10	6.96	7.23
Valine	5.14	5.24	4.95	4.90
Methionine	3.32	3.32	3.46	3.29
Isoleucine	4.52	4.46	4.37	4.26
Leucine	7.70	7.54	7.44	7.17
Tyrosine	3.39	3.31	3.28	3.16
Phenylalanine	4.12	4.05	4.07	3.91
Total amino acid recovery	100.75	101.86	101.58	101.46
Percent essential amino acids	47.00	45.25	45.70	43.71

decreased about 15.5% within the same period of time. Both glycine and proline increased in percentage of the total amino acid concentration. This increase could possibly be due to the lack of enzymatic breakdown of the fish collagens, thereby increasing the percentage of these amino acids as compared with that of the amino acids of the myofibrillar proteins.

In retrospect, an analysis of the raw, unprocessed fish for free amino acids or total nonprotein nitrogen would have made the interpretation of these results more certain.

No marked differences in the amino acid pattern of the standard reference sample could be detected after storing the whole fish in ice for periods up to 11 days. The amino acid pattern of the FPC's produced from the same batch of fish as was the standard reference sample, did, however, show changes, which were more pronounced in the FPC processed from 11-day-old fish. These changes appeared to be the result of alcohol extraction of solubles that were apparently formed during ice storage and not leached out by the melt water from the ice.

PROTEIN QUALITY

STANDARD REFERENCE SAMPLE

Protein efficiency ratios were determined by the method of Campbell (1960). Diets of the standard reference samples and of FPC prepared from raw fish stored in ice were fed *ad libitum* to male albino rats (Charles River strain), which were randomly allotted to groups of 10 animals. The samples were added to a basal diet at a 10% level of crude protein. Gain in weight and consumption of food were recorded each week for 4 weeks, and the protein efficiency ratio was calculated as (weight gain)/(weight of protein consumed). A diet in which casein was the source of protein was used as a reference.

Table 6 shows the data obtained from the animal-feeding studies comparing the quality of the protein of the various samples. Except for the sample prepared from fish held 11 days, the protein quality of the standard reference samples was better than that of casein. The protein quality of the standard reference sample taken on the 11th day was similar to that of casein and therefore was lower than that of the three samples taken earlier.

TABLE 6.—Mean weight gained, food consumed, and adjusted protein efficiency ratio of groups of eight rats fed freeze-dried whole hake prepared from fish stored in ice, compared with casein.

Storage time	Mean weight gained	Mean weight of food consumed	Adjusted protein efficiency ratio[1]
Days	*Grams*	*Grams*	
2	158.6 ± 3.16	390 ± 5.7	3.46 ± .05
6	150.8 ± 3.08	385 ± 5.9	3.35 ± .08
8	155.6 ± 5.28	381 ± 7.7	3.49 ± .07
11	148.6 ± 3.35	400 ± 3.9	3.18 ± .07
Casein	113.5 ± 5.65	323 ± 3.9	3.00 ± .00

[1] The protein efficiency ratios were adjusted to a protein efficiency ratio of 3.00 for casein.

Proximate composition and concentrations of amino acid do not account for the difference obtained in the quality of the protein in the sample of fish held in ice for 11 days. Because the fish were from the same lot and were chosen randomly, we can only speculate either that the utilization (digestibility) of the protein (amino acids) was decreased or that compounds depressing growth were formed during storage.

FISH PROTEIN CONCENTRATE

The same methods were used to determine protein quality as were used with the freeze-dried fish.

Table 7 shows the data obtained from the feeding tests made on FPC's produced from the fish held in iced storage. All the FPC's gave a greater gain in weight and a higher pro-

TABLE 7.—Mean weight gained, food consumed, and protein efficiency ratio of groups of eight rats fed diets of FPC prepared from raw fish stored in ice for periods up to 11 days compared with casein.

Storage time	Mean weight gained	Mean weight of food consumed	Adjusted protein efficiency ratio[1]
Days	*Grams*	*Grams*	
2	154.0 ± 8.63	363 ± 12.0	3.62 ± .05
6	155.1 ± 8.12	362 ± 12.3	3.65 ± .09
8	154.4 ± 4.95	368 ± 7.6	3.59 ± .10
11	145.4 ± 4.80	358 ± 10.3	3.47 ± .10
Casein	113.5 ± 5.65	323 ± 3.9	3.00 ± .00

[1] The protein efficiency ratios were adjusted to a protein efficiency ratio of 3.00 for casein.

tein efficiency ratio than did the casein. Diets containing FPC made from fish stored for 2, 6, and 8 days in ice resulted in protein efficiency ratios ranging between 3.59 and 3.65. The diet containing FPC from the 11-day-old fish yielded a slightly lower gain in weight and a protein efficiency ratio of 3.47. These results agree with those obtained with the standard reference samples made from the same fish. The nutritive quality of the 11-day standard reference samples, however, was poorer than that of the FPC sample. This anomalous result suggests either an improved utilization of protein as a result of extraction with isopropyl alcohol or the removal of some factor that may have depressed growth.

Freeze-dried fish produced from whole red hake stored in ice 2 to 8 days did not differ in protein quality. Freeze-dried fish produced from whole red hake stored for 11 days, however, was lower in protein quality but still had a protein efficiency ratio equal to that of casein. FPC produced from whole fish stored for 2 to 11 days showed no differences in protein quality. All the FPC's had protein efficiency ratios higher than that of casein.

SUMMARY AND CONCLUSIONS

Whole red hake were stored in ice for 2, 6, 8, and 11 days. The fish were organoleptically evaluated for freshness at each storage period and were then processed by freeze-drying to form a reference sample or by solvent extraction with isopropyl alcohol to form a fish protein concentrate. These products were then analyzed for proximate composition and amino acid concentration and for protein quality.

The results of the subjective evaluation for freshness indicated that the fish stored up to 8 days were still acceptable for food but that those stored for 11 days were not acceptable.

The proximate composition and the amino acid concentration of the freeze-dried whole samples of fish showed very little change as a result of the storage of the raw fish in ice. Rat-feeding tests indicated a loss in protein quality of the freeze-dried sample prepared from 11-day-old raw fish. Protein efficiency ratio values ranged from 3.35 to 3.49 for fish stored up to 8 days, whereas the 11th-day sample resulted in a protein efficiency ratio of 3.18. All protein efficiency ratio values, however, were equal to the value for casein or were higher.

The proximate composition of FPC's produced from fish stored up to 8 days in ice remained relatively constant. The crude protein in the concentrate produced from fish stored for 11 days decreased about 2.5%. The concentration of amino acids also followed this pattern with a resultant lowering in the concentration of lysine and a slight increase in that of proline and glycine. The protein quality of the FPC processed from the 11-day-old fish was also slightly lower than that of FPC processed from fresher fish. All FPC's, however, had protein efficiency ratios higher than that of casein.

We conclude that storage of whole hake in ice up to 8 days is a satisfactory means of holding them prior to extracting the ground hake with isopropyl alcohol to produce FPC.

LITERATURE CITED

BROWN, NORMAN L., AND HARRY MILLER, JR.
1969. Experimental production of fish protein concentrate (FPC) from Mediterranean sardines. Commer. Fish. Rev. 31(10): 30-33.

CAMPBELL, J. A.
1960. Evaluation of protein in foods for regulatory purposes. J. Agr. Food Chem. 8(4): 323-327.

COHEN, EDWARD H., AND JOHN A. PETERS.
1963. Effect of storage in refrigerated sea water on amino acids and other components of whiting (*Merluccius bilinearis*). Fish. Ind. Res. 2(2): 5-11.

DUBROW, DAVID, AND OLIVIA HAMMERLE.
1969. Holding raw fish (red hake) in isopropyl alcohol for FPC production. Food Technol. 23(2): 254-256.

HORWITZ, WILLIAM (chairman and editor).
1965. Official methods of analysis of the Association of Official Agricultural Chemists. 10th ed. Association of Official Agricultural Chemists, Washington, D.C., xx + 957 pp.

SMITH, PRESTON, JR., MARY E. AMBROSE, AND GEORGE N. KNOBL, JR.
1964. Improved rapid method for determining total lipids in fish meal. Commer. Fish. Rev. 26(7): 1-5.

SPACKMAN, DARREL H., WILLIAM H. STEIN, AND STANFORD MOORE.
1958. Automatic recording apparatus for use in the chromatography of amino acids. Anal. Chem. 30(7): 1190-1206.

LABORATORY REARING OF THE DESERT PUPFISH, *Cyprinodon macularius*

DAVID CREAR[1] AND IRWIN HAYDOCK[2]

ABSTRACT

The desert pupfish, *Cyprinodon macularius*, may be reared in the laboratory for use in the study of embryology, genetics, physiology, and behavior. It is euryhaline (0-70 ‰) and eurythermal (8°-44.6° C) and may be useful as a bioassay for either freshwater or marine pollutants. In the Salton Sea area of California, the recent introduction of exotic species and the encroachment of civilization have drastically reduced the formerly abundant pupfish populations. Laboratory rearing eliminates the need for continuous exploitation of a rapidly contracting natural population and could supply adequate stocks for sanctuaries, thereby preserving the species from extinction. Laboratory apparatus and conditions are described for maintaining larval and adult pupfish. Parasites and diseases encountered are discussed and successful treatments described. Methods for spawning and rearing the desert pupfish in the laboratory are detailed. These methods may also be applicable to many other species of pupfish that are in danger of extinction.

The desert pupfish, *Cyprinodon macularius* Baird and Girard, is a killifish (Cyprinodontidae) native to the Lower Colorado River Basin from southern Arizona to southern California and the Sonoyta River of northern Sonora, Mexico (Miller, 1948). It thrives under the harsh conditions of the desert environment. It lives in fresh water as well as highly saline pools that few other vertebrates can tolerate. Its ability to survive in such environments, plus other important biological characteristics listed in Table 1, renders it an exceptionally hardy laboratory animal potentially valuable for research in many fields.

POTENTIAL FOR RESEARCH

Desert pupfish has many characteristics favorable for embryological research. It can be spawned with relative ease and can be maintained in the laboratory throughout the year to supply large eggs (approximately 2 mm in diameter), suitable for vital marking and grafting experiments. Other favorable characteristics are the transparent chorion and the long developmental period which can be temperature-controlled (New, 1966). The sticky filaments that are attached to the chorion of its demersal egg can be partially removed by rolling the eggs gently on filter paper 4 to 8 hr after fertilization. Any remaining filaments are matted together and can be easily removed with small forceps.

Desert pupfish, since they mature quickly, could be used for research in fish genetics and on the aging process. Barlow (1961) reported that pupfish reach maturity in the field in 3 months. F_1 pupfish, reared from eggs and maintained at 27° C, were observed spawning in the laboratory approximately 4 months after hatching.

The desert pupfish, a euryplastic species, also possesses physiological and behavioral traits that make it valuable for scientific research. The juveniles can tolerate salinities ranging from fresh water to 90 ‰ (Barlow, 1958). The adults, although less euryhaline, are known to spawn in salinities as high as 70 ‰ (Kinne and Kinne, 1962). The salinity tolerance of newly hatched pupfish render them potentially useful for comparative bioassay of freshwater and marine pollution. The extreme temperature tolerance is an additional asset. Desert pupfish

[1] Formerly, California Department of Fish and Game, Inland Fisheries Branch, Sacramento, Calif.; present address: School of Public Health, 1890 East-West Road, University of Hawaii, Honolulu, Hawaii 96822.

[2] Formerly, California Department of Fish and Game, Inland Fisheries Branch, Sacramento, Calif.; present address: Southern California Coastal Water Research Project, 10845 Lindbrook Drive, Los Angeles, Calif. 90024.

Manuscript received September 1970.

TABLE 1.—Biological characteristics of the desert pupfish, *Cyprinodon macularius*, and other important fish in research.[1]

Items	Desert pupfish, *Cyprinodon macularius*	Trout: *Salmo trutta*, *S. gairdneri*	Killifish, *Fundulus heteroclitus*	Medaka, *Oryzias latipes*
Salinity tolerance:				
Adults	0-70 ‰	Euryhaline	Marine-estuarine	Fresh water
Eggs	0-90 ‰	Fresh water	Wide tolerance	— ? —
Natural spawning season	April to October[2]	Spring or fall	June to August	April to October
Artificial spawning	Spawns naturally all year, cannot be stripped	Seasonal spawning, eggs are stripped	Seasonal spawning, eggs are stripped	Spawns naturally all year, eggs can be stripped
Egg type	Demersal; transparent	Demersal; opaque	Demersal; transparent	Demersal; transparent
Egg diameter	Ca. 2 mm	Ca. 5 mm	Ca. 2 mm	Ca. 1 mm
Incubation temperature Range	13°-36° C; at 20° C, 10 days	3°-13° C; at 10° C, 34-37 days	15°-27° C; at 20° C, 9.5 days	13°-25° C; at 25° C, 8 days
Length of adult	4-5 cm	15-30 cm at first spawning	8-12 cm	2-4 cm
Age at maturity	3-4 months	2-4 years	1-2 years (?)	1-2 months

[1] Data compiled from: Barlow, 1958, 1961; Frost and Brown, 1967; Kinne and Kinne, 1962; Miller, 1970 (personal communication); New, 1966; Rugh, 1962; Trinkaus, 1967; Yamamoto, 1967.
[2] Desert pupfish has not been recorded spawning throughout the year in nature as have other species of pupfish but presumably would do so under the proper conditions (Bunnell, 1970).

have been found in the field at temperatures ranging from 8° to 44° C (Lowe and Heath, 1969; Kinne, 1960).

Since it can be relatively easily spawned in the laboratory, the desert pupfish is a good model for the study of reproductive behavior. Numerous and rapid behavioral sequences precede the actual spawning act. On occasion, however, fish in high spawning readiness eliminate many behavioral sequences and commence spawning immediately. When properly stimulated the fish swim parallel to one another, the male slightly behind the female, twist into an S-curve, and spawn. Release of the gametes is accompanied by a quivering movement of both fish. The male wraps his anal fin under the female's vent and fertilizes each egg as it is extruded. The female then dips, leaving the fertilized egg attached to the substrate. This process is repeated until the female is spent, having spawned 50 to 200 eggs in about 2 hr under laboratory conditions. In nature the female only rarely spawns more than one or two eggs in succession (Barlow, 1961). The mature male is easily recognized by his aggressiveness and his brilliant, blue coloration. The pugnacious male pupfish must be separated in the laboratory from females and other males. The determination of the male to spawn, regardless of circumstances, makes the pupfish a potentially valuable species for classroom demonstrations. Barlow (1961) has presented a complete and detailed description of the social and reproductive behavior of the desert pupfish.

LABORATORY REARING THE DESERT PUPFISH FOR CONSERVATION

Another value in rearing desert pupfish lies in the preservation of the species. Today the pupfish faces elimination from many areas of its natural range due to predation and competition from exotic species and the modification or destruction of its habitat. Large populations of desert pupfish, once prevalent around the Salton Sea, have been alarmingly reduced. At the present rate of population reduction, the species may well become extinct in this area in the near future unless steps are taken to insure its survival. Artificial rearing is one of the possible means.

Coleman (1929) conducted an ecological survey of the Salton Sea for the California Depart-

ment of Fish and Game and judged that the numbers of mosquitofish, *Gambusia affinis*, and desert pupfish were sufficient to support a large population of carnivorous game fish. Cowles (1934) reported the pupfish populations to be exceedingly large in and around the Salton Sea. In 1956 Barlow (1961) observed schools of juvenile pupfish of nearly 10,000 individuals. He estimated that one large, isolated, shore pool at the Salton Sea contained 150 adults per square meter. Today, in the Salton Sea area desert pupfish are almost totally confined to a few tributaries. In response to the severe reduction of pupfish populations in the Salton Sea area, Jack Hesemeyer, Supervisor of the Anza-Borrego State Park, has built a pupfish sanctuary near the Park headquarters at Borrego Springs. This small sanctuary was stocked on June 24, 1970, with 48 laboratory-reared fish produced by the techniques outlined below. Several hundred additional fish were placed in the Palm Canyon pools nearby.

The authors hope that this article, in addition to demonstrating the value of the desert pupfish as a teaching and research animal, will help in its preservation by describing laboratory-spawning methods that can provide adequate stocks for sanctuaries in natural and artificial habitats. In addition, the rearing techniques described here for desert pupfish may be useful for the preservation of many other species of pupfish that are in danger of extinction.

MATERIALS AND METHODS

The desert pupfish used to develop spawning techniques were seined from an irrigation ditch emptying on the northwestern shore of the Salton Sea in Riverside County, Calif. Specimens were transported in plastic garbage pails filled with aerated ditch water to the Fishery-Oceanography Center at La Jolla, Calif. We found that the water temperature during transport should not be allowed to fluctuate radically from that at which the fish are found.

Many of the specimens collected were infected by a freshwater parasitic copepod of the family Lernaeidae (possibly introduced with home-aquarium fish). The large egg cases of this copepod were clearly visible on the fish, usually at the base of the fins. Individuals carrying this parasite were weak and commonly died during or soon after transport. Reichenbach-Klinke and Elkan (1965) recommend a salt bath (NaCl, 0.76-1.1%) to eliminate such copepods. To treat this infection, all fish on arrival at the laboratory were converted to seawater over a 5-day period. Kinne (1960) reported that a 1-month-old pupfish can survive sudden salinity changes up to 35 ‰, whereas 1-year-old adults cannot survive sudden salinity changes of more than 10 to 15 ‰. Robert R. Miller (1970, personal communication), however, reports that in 1937 he found that this species could be shifted with ease directly from fresh water to seawater and back. After conversion to seawater all traces of the parasitic copepod vanished. Toward the end of the experiment, several fish died from a devastating protozoan infection in the epithelial tissue surrounding the mouth. The tissue appeared bloody and often had completely disintegrated. Many apparently healthy fish died with little or no warning in less than 12 hr. The marine parasitic protozoan, *Cryptocaryon irritans*, prevalent in the Scripps water system was suspected (Wilkie and Gordin, 1969). The surviving fish were transferred back to fresh water and, fortunately, the parasite failed to make the transition.

LABORATORY CONDITIONS

The fish were maintained in 20-gal tanks with subsurface filters covered with crushed oyster shell. The water was changed completely and the shell washed approximately every 6 weeks. Four individuals were isolated in each aquarium by plastic, perforated dividers. The tanks were maintained at room temperature, 20° to 22° C. Standard aquarium heaters were used whenever higher temperatures were needed. No attempt was made to control pH other than the use of the crushed oyster shell substrate.

The fish were fed frozen adult brine shrimp, *Artemia salina*, three times daily during the week and once a day on weekends. Kinne (1960) and Kinne and Kinne (1962) used two species of

worms (*Enchytraeus albidus*[3] and *Tubifex* sp.), two species of crustaceans (*Daphnia* and *Cyclops*), beef liver, fresh lettuce, spinach, and several brands of commercial fish food.

The fish were subjected to a daily 16-hr light and 8-hr dark cycle. The lighting used was a combination of daylight fluorescent bulbs and mercury vapor arc lamps. Most fish were ready to spawn under these conditions within 3 weeks of capture, although there was marked seasonal and individual variation. Observations made suggest the length of the light period is more important than light intensity for the induction of spawning. Kinne and Kinne (1962) reported using a 14L-10D cycle with a combination of fluorescent tubes and natural daylight.

SPAWNING METHODS

The fish were spawned on a varied schedule, depending on the readiness of the female. The average female spawned 50 to 200 eggs, depending upon her size, approximately once a week. One large, exceptionally prolific female spawned 200 eggs twice a week for 2 months. Subsequently, this female was not spawned on schedule, became eggbound, and was unable to extrude her eggs. After her death the large, single ovary contained over 800 eggs and accounted for 44 % of the total body weight. Females that would not spawn at room temperature were spawned at 27° C. Females that could not spawn at either room temperature or 27° C were removed from isolation to a community tank (4 females, 2 males) on a 12L-12D photoperiod, wherein they quickly spawned out their eggs at 27° C. Kinne (1960) reported that the fish do not spawn in the laboratory at temperatures below 20° C and seem to spawn optimally between 28° and 32° C. He also noted that the temperature in the field varies between 25° and 35° C for most of the spawning season.

Kinne and Kinne (1962) reported that pupfish embryos have one period of low thermal stability between fertilization and gastrulation and a second period just before hatching. Observations made during our study indicate another period of low thermal stability just before fertilization. When a female maintained at room temperature is transferred to a higher temperature to induce spawning, most of the eggs either are not fertilized or do not develop. We found that females should be maintained and spawned at one temperature. If maintained at a temperature above 25° C, they will need to be spawned regularly; otherwise, the eggs are dropped to the bottom of the aquarium unfertilized. A more flexible spawning schedule is possible if the female is kept at a lower temperature.

The fish were spawned in white, plastic, food containers measuring 27 × 20 × 10 cm, containing 2.5 liters of water at 22° C. Immediately after the spawning these containers were suspended in a water bath at 27° C. This technique produced good hatches in spite of the reported low thermal stability between fertilization and gastrulation (Kinne and Kinne, 1962). The water bath was a 20-gal tank with a standard aquarium heater.

Either a green plastic mat or white cheesecloth was used as a substrate on which the females could attach the adhesive eggs. On several occasions, when the plastic mat was used, the pupfish were observed eating the previously spawned eggs, which were readily visible against the green background. The substitution of cheesecloth with L-shaped glass-rod weights at its periphery successfully reduced parental egg consumption. The cheesecloth was a superior substrate because many of the eggs were buried in the material and thus were inaccessible to the parents. Furthermore, the combination of a white spawning bin, white cheesecloth, and nearly transparent eggs made the latter virtually invisible to the experimenters and, presumably, to the fish.

The parent fish were well fed prior to spawning to help reduce the number of eggs consumed. The spawning bin, containing the female, was placed in a quiet location. Five to fifteen min later the male was introduced to the spawning bin which was then left undisturbed for 1 to 2 hr. Barlow (1961) reported that spawning

[3] See Kinne (1960) for details on mass culturing *Enchytraeus albidus*.

lasts from 30 min to 2 hr, depending on the size of the female and the number of eggs laid. In order to prevent the serious injury or death of the female, the male was not left in the spawning bin for longer than 2 hr. After termination of spawning the fish were returned to their aquaria and the feces were removed from the container. The spawning bin was then suspended in a 27° C water bath with aeration. Kinne and Kinne's (1962) data on hatching shows that any incubation temperature between 24° and 30° C should produce hatches of at least 80 % in 100 % air-saturated seawater. Pupfish eggs left at room temperature in the laboratory at La Jolla suffered extremely high mortalities owing to daily temperature fluctuations between 18° and 24° C. Kinne and Kinne (1962) supplied data on egg mortalities and incubation periods at different temperatures from 10° to 37° C.

Hatching success of different breeding pairs varied unexplainably under constant conditions. A large sample of eggs from one breeding pair showed, however, that salinity and temperature markedly effected the hatching success of pupfish eggs (Table 2). Eggs in small clusters, apparently laid at nearly the same instant, seldom hatched. Kinne and Kinne (1962) also reported reduced development and increased mortalities for conglomerated eggs.

Pupfish larvae are large enough (5.5 mm total length at 27° C in 50 % seawater) to feed from the day of hatching on brine shrimp nauplii (Salt Lake variety), *Artemia salina*. The larvae when handled were drawn with a bulb into a long glass tube. Kinne and Kinne (1962) gave extensive data on the growth, food intake, and food conversion for pupfish larvae at different temperatures and salinities.

TABLE 2.—Hatching success of desert pupfish eggs.

Salinity	Temperature	Eggs			
		Developing		Dead	Total
	° C	No.	%	No.	No.
Fresh water	22	74	54.0	66	140
	27	4	5.4	70	74
	27	3	5.0	57	60
Half seawater	27	92	85.1	16	108
Seawater	27	17	29.6	40	57
	27	13	29.5	31	44
	27	7	16.6	35	42

CONCLUSIONS

The desert pupfish may be reared in the laboratory over a wide range of temperatures and salinities. Half-strength seawater at 27° C provided the best hatch observed during this study. The pupfish is a hardy laboratory animal that does well in captivity if proper attention is paid to food, space, and hygiene. However, a note of caution should be added, since we reared only two generations of pupfish. Bunnell (1970) states that when a pupfish stock is bred in captivity from a single pair, the fish do well at first, but gradually die out over several generations. This possibility should be further substantiated before committing experimental studies to a single line of descent.

The authors believe that the desert pupfish is an excellent experimental animal for many types of biological research. Studies of the systematics (Miller, 1948), behavior (Barlow, 1961), and physiology (e.g., Kinne and Kinne, 1962) provide a wealth of background information on the basic biology of pupfish which will prove valuable to investigators interested in using this species in teaching and research. Other reports (e.g., Bunnell, 1970) indicate the critical status of some species of *Cyprinodon*, including *C. macularius*, and point out the need to provide sanctuaries to avoid extinction of this unique species. Laboratory rearing of pupfish will not only provide material for scientific observation and experimentation, but will also remove some of the pressure on an already rapidly contracting natural population by providing adequate stocks for present and future sanctuaries. Both measures should enhance the value of the desert pupfish and emphasize the importance of saving the species from extinction.

ACKNOWLEDGMENTS

The authors wish to extend their deep appreciation to Robert Rush Miller and Carl Hubbs for their valuable suggestions and extensive editing of this manuscript.

LITERATURE CITED

Barlow, George W.
1958. High salinity mortality of desert pupfish, *Cyprinodon macularius*. Copeia 1958(3): 231-232.
1961. Social behavior of the desert pupfish, *Cyprinodon macularius*, in the field and in the aquarium. Amer. Midl. Natur. 65(2): 339-359.

Bunnell, Sterling.
1970. The desert pupfish. *In* Pupfish of the Death Valley region. Cry Calif. 5(2): 2-13.

Coleman, George A.
1929. A biological survey of Salton Sea. Calif. Fish Game 15(3): 218-227.

Cowles, Raymond B.
1934. Notes on the ecology and breeding habits of the desert minnow, *Cyprinodon macularius* Baird and Girard. Copeia 1934(1): 40-42.

Frost, W. E., and M. E. Brown.
1967. The trout. Collins, London. 286 p.

Kinne, Otto.
1960. Growth, food intake, and food conversion in a euryplastic fish exposed to different temperatures and salinities. Physiol. Zool. 33(4): 288-317.

Kinne, Otto, and Eva Maria Kinne.
1962. Rates of development in embryos of a cyprinodont fish exposed to different temperature-salinity-oxygen combinations. Can. J. Zool. 40(2): 231-253.

Lowe, Charle. H., and Wallace G. Heath.
1969. Behavioral and physiological responses to temperature in the desert pupfish *Cyprinodon macularius*. Physiol. Zool. 42(1): 53-59.

Miller, Robert R.
1948. The cyprinodont fishes of the Death Valley system of eastern California and southwestern Nevada. Misc. Publ. Mus. Zool. Univ. Mich. 68. 155 p.

New, D. A. T.
1966. The culture of vertebrate embryos. Logos Press, Academic Press, London. x + 245 p.

Reichenbach-Klinke, H., and E. Elkan.
1965. The principal diseases of lower vertebrates. Academic Press, London. 600 p.

Rugh, Robert.
1962. Experimental embryology. Burgess Publishing Company, Minneapolis. 501 p.

Trinkaus, J. P.
1967. *Fundulus*. *In* Fred H. Wilt and Norman K. Wessells (editors), Methods in developmental biology, p. 113-122. Thomas Y. Crowell Company, New York.

Wilkie, Donald W., and Hillel Gordin.
1969. Outbreak of Cryptocaryoniasis in marine aquaria at Scripps Institution of Oceanography. Calif. Fish Game 55(3): 227-236.

Yamamoto, Toki-o.
1967. Medaka. *In* Fred H. Wilt and Norman K. Wessells (editors), Methods in developmental biology, p. 101-111. Thomas Y. Crowell Company, New York.

GONAD MATURATION AND HORMONE-INDUCED SPAWNING OF THE GULF CROAKER, *Bairdiella icistia*[1]

IRWIN HAYDOCK[2]

ABSTRACT

Successful methods of capture, transport, disease treatment, and laboratory maintenance of the gulf croaker, *Bairdiella icistia*, are described. Gonad maturation was achieved out of season by the use of appropriate controlled photoperiods, temperatures, and abundant feeding. Mature fish or fish brought to maturity in the laboratory were spawned with suitable hormone injections and the time of spawning could be accurately predicted. Eggs obtained from hormone-induced spawning were normal in all respects and the larvae were reared through metamorphosis using rotifers and brine shrimp nauplii as food; thus, the life history of this marine fish can, for the first time, be completed under controlled laboratory conditions. The techniques developed for croakers may have application to mariculture, biossay of marine pollution, and in more general research on marine fish reproduction.

Reproduction in fishes which spawn annually is controlled by the interaction of exogenous and endogenous stimuli, particularly the endocrine activity of the pituitary-gonadal axis which is indirectly influenced by environmental factors such as day length and temperature. Against this basic background, which determines the gonadal maturation cycle, the actual spawning act is controlled by neurohumeral and neuromuscular connections activated by rapidly changing environmental parameters and behavioral cues (Liley, 1969; Malven, 1970). This basic reproductive pattern and the lacunae in our understanding of it have recently been reviewed in detail (Breder and Rosen, 1966; Hoar, 1969).

Much of the work on reproductive physiology of fishes has been done with freshwater species of interest to aquarists (Wickler, 1966) or experimentalists (New, 1966; Hoar, 1969; Liley, 1969). There is, however, no reason to suspect that the basic features of reproduction, elucidated with freshwater species convenient to maintain, will differ significantly from those of marine forms, which require more elaborate facilities for study.

Because of increasing demand for fish as a source of protein, as well as for sport and for scientific studies on reproductive success of fishes in generally deteriorating natural environments, there are now intensive and extensive efforts to artificially culture commercially valuable freshwater species (Hickling, 1962; Hora and Pillay, 1962; Bardach, 1968). Recent interest has also focused on mariculture, the cultivation of marine species. Some success has been achieved in Great Britain (plaice and sole—Shelbourne, 1964 and 1970), Japan (bream and yellowtail—Harada, 1970), and in the United States (pompano—Finucane, 1970). However, all such cultures are started either with young fish caught at sea or with eggs spawned in the sea or stripped from mature fish captured during their normal spawning season. The field work necessitated by this method can be costly and unpredictable, drawbacks which are compounded by the difficulty usually experienced in simultaneously finding running-ripe fish of both sexes, especially females. These problems are avoided in the culture of salmonids because of the unique determination of the fish to return to the same place to spawn at a fairly predictable time (Leitritz, 1959). The grunion is a striking

[1] This research was supported, in part, by Federal Aid to Fish Restoration Funds, Dingell-Johnson Project California F-24-R, "Salton Sea Investigations."

[2] Formerly, California Department of Fish and Game, Inland Fisheries Branch, Sacramento, Calif.; present address: Southern California Coastal Water Research Project, 18045 Lindbrook Drive, Los Angeles, Calif. 90024.

Manuscript received September 1970.

example of a marine fish showing similar determination (Walker, 1952).

The necessity of working with the reproductive products of one species only during its normal spawning season is one of the major obstacles faced by experimentalists and fish culturists. Most species of temperate and high latitudes show rather well-defined, short spawning seasons, probably related to the annual cycle of day length, temperature, and associated productivity. This seasonality generally means that experimental work proceeds at a hectic pace for a short time and then must be dropped or switched to another species available in breeding condition. This causes numerous difficulties, delays, and expenses for both research and researcher. The answer to this problem is to artificially induce maturation and spawning under controlled laboratory conditions.

To my knowledge, artificial gonad maturation under controlled conditions of light and temperature, hormone-induced spawning, and laboratory rearing of the fragile larvae through metamorphosis have not been accomplished for any single marine fish prior to this time. Pompano have been spawned with hormones, but the fertilized eggs did not hatch (Finucane, 1970). A euryhaline form, *Fundulus heteroclitus*, has been spawned with pituitary extract (Joseph and Saksena, 1966); however, only mature fish recently obtained from their natural environment were used.

Protocols for hormone-induced spawning of numerous species of freshwater fishes is well established (Dodd, 1955; Fontenele, 1955; Clemens and Sneed, 1962). A useful review of literature on the effects of hormones in fishes (Pickford and Atz, 1957) has been updated with a comprehensive, annotated bibliography (Atz and Pickford, 1964), and a timely review of various aspects of reproductive physiology of fishes is also available (Hoar and Randall, 1969, 1970).

Hormone-induced spawning is an accepted part of several commercial fish culture ventures and will be used in many more when techniques become reliably standardized for various species. Brazilians pioneered the use of hormones in spawning carp, while in Russia, where hydroelectric dams block the spawning migrations of sturgeons and salmonids, hormone-induced spawning has been practiced for many years (Atz and Pickford, 1959). In India, carps spawn naturally in flowing streams but must be injected with conspecific pituitaries before they will spawn in ponds (Chaudhuri, 1960; Das and Khan, 1962). Catfish respond to similar treatment (Sundararaj and Goswami, 1968). In the United States, several freshwater and anadromous species are spawned with hormones (Ball and Bacon, 1954; Clemens and Sneed, 1962; Stevens, 1966).

My investigation focused on the use of hormones in inducing maturation and spawning of the gulf croaker, *Bairdiella icistia* (Jordan and Gilbert), both for the specific purpose of obtaining eggs for physiological studies of salinity tolerance and for the more general purpose of studying factors which influence spawning in marine fishes. Once success had been achieved in spawning fish under controlled laboratory conditions, the influences of biological and physical factors on the spawning process were examined in detail.

THE SALTON SEA FISHERY

The Salton Sea is a large, saline, inland lake in the lower desert of southern California. The present body of water was formed when the flood waters of the Colorado and Gila Rivers broke through irrigation dikes in 1905 and poured into the then dry Salton Sink. The irrigation canals were repaired and the water again brought under control in 1907. Subsequently, the Salton Sea was declared an agricultural sump for the deposition of large quantities of irrigation waste water. This water leached large quantities of salt out of the surrounding agricultural land and carried it into the sea. Consequently, over the years the salinity gradually increased. Short-term fluctuations occurred—reflecting changes in inflow, annual rainfall, surface area, temperature, and evaporation. The salinity of the Salton Sea in 1970 is about 37 ‰.

During the period 1950-56, when the salinity of the Salton Sea approximated that of the ocean,

the California Department of Fish and Game transplanted a variety of fishes from the Gulf of California with the intent of establishing a productive sport fishery. The present fishery stems from the descendants of a total original introduction of 57 gulf croaker, 67 sargo, *Anisotremus davidsoni*, and 100 to 200 orangemouth corvina, *Cynoscion xanthulus*, transplanted to Salton Sea in 1951-52 (Walker, 1961; Whitney, 1967). The fishes thrived and developed large populations in the simple, man-made ecosystem, but increasing salinity now threatens the continuing existence of the famous fishery.

The Salton Sea Investigations was a joint Federal-State project whose overall goal was to predict a target salinity at which a water quality control project could be aimed that would not be detrimental to the present highly esteemed fishery. Engineering studies had suggested a method by which the salinity of the Salton Sea could be controlled, but the maximum permissible salinity levels still had to be established on the basis of biological information. Other sciaenid species live in the Gulf of Mexico in a wide range of salinities up to 75 ‰, but it is considered unlikely that spawning occurs in extremely high salinities or that the larvae could tolerate such osmotic stress (Gunter, 1967; Hedgpeth, 1959).

To attain our goal in the short time available, we have developed all of the necessary techniques for spawning Salton Sea fishes under controlled laboratory conditions. These techniques have proved successful for obtaining viable spawn for the necessary salinity tolerance studies of both croaker and sargo.[3] I had originally assumed that the close relationship of gulf croaker to corvina, both of the family Sciaenidae, would make it possible to apply croaker spawning techniques directly to the corvina. However, the carnivorous nature of corvina and the general difficulty of handling this powerful fish in the laboratory demanded special feeding and holding techniques and precluded successful laboratory spawning. Hormone-induced spawning has been achieved in our laboratory with other mature marine fishes, including *Eucinostomus* sp. (family Gerridae), *Genyonemus lineatus* (Sciaenidae), and sargo (Haemulidae). The techniques developed for inducing spawning with hormones in gulf croakers may thus have general applicability.

[3] Reuben Lasker and Richard R. Tenaza. 1968. Salton Sea fish larvae investigation progress report: techniques and preliminary experiments on osmotic stress (spring-summer 1968). Inland Fisheries Administrative Report No. 68-7, Oct. 1968, (Unpublished).

METHODS

CAPTURE, TRANSPORT, CARE, AND HANDLING OF FISH

Two year classes of gulf croakers were captured with a 60-m beach seine in May and October 1969. The first sample consisted of mature fish, 1 year old, and the second of young-of-the-year fish which were subsequently matured under controlled photoperiod and temperature conditions in the laboratory. The fish were captured on sandy beaches north of the U.S. Navy Base and north of the Salton Bay Marina, both on the west side of the Salton Sea. A beach seine is the most dependable method for capturing large numbers of these fish in good condition, except in midsummer and late winter, when fish are unavailable near shore.

The fish were transported to La Jolla, Calif., in a 500-liter tank equipped with aeration and filtration devices. In transport, and for several subsequent days in the laboratory, the fish were treated with Furacin antibiotic[4] at an initial concentration of 250 mg/3.8 liter. Several early failures showed that careful handling, high standards of water quality, and, especially, antibiotic treatment are all essential to high survival rates of Salton Sea fishes after capture.

In the laboratory, the fish were held in 2,000-liter rectangular tanks (2 m × 1 m × 1 m deep) supplied continuously from the seawater supply of the Fishery-Oceanography Center in La Jolla. A general description of this extraordinary facility is available (Lasker and Vlymen, 1969). A water temperature of 22 ± 1° C was main-

[4] Sharpe and Vejar, Los Angeles, Calif. Use of trade names is merely to facilitate descriptions; no endorsement is implied.

tained except for special studies or for short maintenance periods. An artificial photoperiod of 16 hr light:8 hr dark (16L:8D) was maintained by time clocks (Tork, Model 7100[5]) in a light-tight room with 400 w, white mercury lamps (Sylvania, H33-1-GL/C[5]), suspended 1.5 m above the water surface at the center of each tank. Deviations from this water temperature and light schedule are reported where appropriate.

Young fish, less than 13 cm in length, were fed 0.238 cm Oregon Moist Pellets[6] from Allen automatic trout feeders[7] activated with time clocks (Paragon Model 4001-0[8]). As fish grew larger their consumption of pellets diminished until they were fed exclusively on squid which was ground semifrozen into pieces ranging from 0.5 to 2.5 cm^2. All fish were fed squid ad libitum twice daily during the week and once a day on weekends. I consider adequate feeding to be an important factor in gonad maturation, but it was not a variable in this study. In the laboratory, young fish doubled their weight in 2 months and, later, added about 10 g each month, reaching 80 to 100 g by the end of the first year. Salton Sea fish weigh 40 to 50 g at the end of 1 year; the largest gulf croaker caught during this study weighed 420 g.

Initially, and for later studies of the effects of a series of hormone injections, fish were never disturbed without first draining the tanks to within 10 to 15 cm of the bottom and then adding anaesthetic until the fish could be touched without causing a sudden reaction. Fish to be injected were then removed and completely anaesthetized for 1 to 3 min in MS-222 (Tricaine Methanesulfonate)[9] at 0.6 g/3.8 liters. Treated fish were replaced in fresh seawater; if necessary, fish were held with gloved hands and moved rapidly back and forth at the surface to aerate the gills and assist their recovery. There is little danger of fish mortality when the anaesthetic is properly used, and no adverse effects on fish reproduction were found. Later, experience enabled us to net unanaesthetized fish rapidly and place them directly into buckets with MS-222 until they were unconscious. This was done routinely when spawning techniques were thoroughly known.

Fish were individually marked with subcutaneous injections of a 65 mg/ml stock solution of Bismark Brown or Fast Turquoise PT.[10] Hormone, antibiotic and other injections were carried out with 0.5- to 1.0-cc disposable syringes fitted with 25- to 26-gauge, 1.27- to 1.90-cm (½-¾ inch) needles. Needles 0.95 cm (⅜ inch) long proved useful for intraperitoneal (ip) injection where internal damage was possible, but these allowed too much fluid to escape when intramuscular (im) injections were used. In most cases the needle was carefully slipped into the skin between scales, and carrier fluid (oil and saline) was slowly injected into the deep muscles of the back adjacent to the dorsal fin. Slow withdrawal and pressure over the wound site helped to retain most of the fluid. Sesame oil was used in most cases as a carrier, but no essential differences were noted between oil and Holtfreter's saline injections.

LIST OF HORMONES AND THEIR PREPARATION

1. Oxytocin (Pitocin, Pituitary grade I).[11] Injectable solution, 20 IU/ml, used as obtained and stored at 4° C.
2. Deoxycorticosterone Acetate (DOCA, grade II).[11] Injected as a slurry in sesame oil.[12]
3. Human Chorionic Gonadotropin (HCG, stock No. CG-2).[11] Anhydrous powder was made to volume with Holtfreter's saline just prior to injection.
4. Gonadotropin from Pregnant Mare's Serum (PMS).[11] Powder dissolved in distilled water and stored at —10° C.
5. Carp Pituitary (freeze-dried powder).[13]

[5] Pacific Wholesale Electric Company, San Diego, Calif.
[6] R. V. Moore Company, La Conner, Wash.
[7] G-Z Company, Sacramento, Calif.
[8] J. F. Zwiener Company, San Diego, Calif.
[9] Crescent Research Chemicals, Scottsdale, Ariz.
[10] Allied Chemical Company, San Francisco, Calif.
[11] Sigma Chemical Co., St. Louis, Mo.
[12] A. Sahadi Co., Moonachie, N.J.
[13] Stoller Fisheries, Spirit Lake, Iowa.

Powder was homogenized wt/vol in sesame oil or Holtfreter's saline.

6. King Salmon, *Oncorhynchus tshawytscha*, Pituitary.[14] Glands removed and placed in acetone for extraction within 15 min of spawning. Whole glands were homogenized wt/vol in sesame oil or Holtfreter's saline.

Multiple intramuscular (im) or intraperitoneal (ip) injections were accompanied with 200 IU Potassium Penicillin G and 0.025 mg active Streptomycin Sulfate. Fish that were handled several times, with disposable plastic gloves, were routinely treated with Furacin water-mix antibiotic (Vet. grade), at an initial concentration of 250 mg/3.8 liters.

PREPARATION OF SALMON PITUITARIES

Early in the project my attention was directed to the possible usefulness of fish pituitaries for inducing spawning (Pickford and Atz, 1957; Clemens and Sneed, 1962; Atz and Pickford, 1964). Carp pituitaries are commercially available, but there is no assurance that these are removed from spawning fish, a time at which the glands are assumed to have high titers of spawning hormones. Glands from *Bairdiella*, taken during the spawning season, would be ideal, but the bony nature of the brain case makes their removal difficult and their small size makes the effort relatively unrewarding. Spawning grunion, *Leuresthes tenuis*, are seasonally abundant locally but, again, collecting a large number of glands would require great effort. Salmon provide a convenient source of fish pituitaries, since they are available in large numbers at fixed locations (fish hatcheries). Each gland is of considerable size (about 13 mg dry weight), and the bony brain case is reduced to a soft cartilage by decalcification near the time of spawning. Each fish is graded at the hatchery so that spawning females are only sacrificed when at the peak of running ripeness. Fish return to spawn at different times at various hatcheries which allows some flexibility in the timing of collecting operations. All these advantages, plus the fact that the glands proved useful in spawning croakers, justify a detailed discussion of the method developed by Nimbus Hatchery personnel for removing the pituitary from king salmon. I thank W. H. Jochimsen and D. R. Von Allmen for originally demonstrating this technique to me.

A technique for removing pituitary glands from salmon with a special tool exists (Tsuyuki, Schmidt, and Smith, 1964), and similar equipment was available at the Nimbus Hatchery. However, hatchery personnel have developed a simple and rapid technique which allows one person, with a little practice, to directly remove 100 to 200 pituitary glands during the course of a morning's spawning activities at the hatchery. The number of fish spawned limits the number of glands obtained; several hundred fish are spawned each week during November, the peak season at Nimbus Hatchery. The largest numbers of fish enter the hatchery ponds from the river on overcast days or during winter rains.

Female and male pituitary glands were removed from spawned fish within 15 min of death (unfortunately, following death, a severing of the head artery which bleeds the fish often destroys the pituitary in the process). The fish to be used for pituitary extraction are held upright with the gill cover slipped over a sharp stake clamped to a table. A large, sharp butcher knife is used to slice through the cartilaginous tissue of the brain case, parallel to the jaw and just above the level of the eye (a metal glove, as worn by fish-market personnel, would be useful for this step, which is carried out while the neuromuscular system of the large fish is still active). A rubber coat and rubber boots are also necessary accouterments at this gross stage of dissection. The cut exposes the brain, or, if at the appropriate depth, the pituitary stalk (sometimes the gland itself) is severed and the gland can be removed from its cavity with a pair of forceps or a narrow scoop. Some cuts, at odd angles, sever nerve cords as well as the pituitary stalk and expose three cavities. Once learned, the location, consistency, and color of the pituitary differentiate it from nervous or other fatty tissues with which it might be confused. At first, shallow cuts can be made to

[14] Nimbus Fish Hatchery, Rancho Cordova, Calif.

expose the brain; the gland's cavity and stalk are readily seen when the brain is lifted from its cavity and the entire gland can be removed with forceps. A direct approach is more appropriate to the speed with which spawning activities proceed and 1 day of practice is sufficient to enable one person to remove glands as fast as fish are available without undue loss of damaged or partial pituitaries.

The glands are placed directly in chilled acetone until spawning and gland-taking activities are finished. The acetone is decanted and replaced 2 or 3 times over a period of 3 days until all loose material is washed away. The final wash of acetone is decanted, and the glands are blotted gently on filter paper, placed in tightly stoppered vials, and kept at —10° C in a jar of desiccant. Glands stored 1 or 2 years by this method showed no detectable loss of activity.

It was found that pituitaries were easier to homogenize if they were not completely dried. Just prior to preparing a stock solution, the glands were removed from vials, air-dried for a few minutes, and weighed. They were then immediately placed in glass tissue grinders and homogenized in sesame oil or saline. The resulting brei was finely divided and was used unfiltered without clogging 25- and 26-gauge needles. Stock solutions (1-10 mg/ml) were stored in rubber-capped serum bottles (5 ml) at —10° C. All injections were 1.0 to 0.5 ml im and up to 1 ml ip. I used oil rather than saline in most cases on the assumption that oil may slow the rate of absorption and more evenly distribute the hormone.

EVALUATING THE EFFECTS OF HORMONE TREATMENT

Three basic criteria—gonad index, spawning, and fertilization of eggs—were chosen to test the effects of gonadotropin injections. Development of fertilized eggs to hatching is also a useful test of the absolute success of the hormone treatment used to obtain spawn, but hatching success is also very sensitive to other factors, e.g., salinity, temperature, dissolved oxygen, and bacterial contamination.

A commonly used measure of the effects of hormone treatment is the gonosomatic index (GSI) which expresses wet gonad weight as a percent of total wet body weight. The GSI is a reasonable measure of the state of reproductive maturity of a fish. Its measurement, of course, requires that the fish be sacrificed. Histological examination of gonads or measuring egg diameters to assess the stage of maturation are more elaborate approaches which were not used after it was found that GSI accurately predicted spawning readiness of the fish. McInerney and Evans (1970) have shown a direct relationship between GSI and the histological index in female threespine stickleback. Among more recent approaches to this problem is Stevens' (1966) development of a technique for removing eggs from striped bass by means of a catheter. He was able to determine the stage of the eggs and predict the time of optimal ripeness with a fair degree of accuracy.

Samples of 4 or 5 fish were used to assess the effects of hormone treatment. Controls of uninjected or sham-injected groups of fish were maintained where these were appropriate to understanding the effects of hormone treatments on GSI. The GSI of laboratory-held fish varied, understandably, through time, and the effects which this had on the results obtained are discussed where appropriate. The dates of most experiments are given to help explain this variation.

Two fundamental processes in spawning, hydration and ovulation, were evaluated separately with respect to various hormone treatments. Hydration was measured as an increase in total body weight over a period of 1 to 2 days after injection, a process distinct from gonad growth which occurs over longer time periods. This rapid weight gain is due mostly to water uptake by the fish and is reflected in much higher GSI values, as most of the water appears to go into the gonad. Externally, a hydrated fish is grossly bloated, and, in some cases, the fish are listless and remain motionless on the bottom of the tank. Ovulation was assessed by attempting to strip eggs from fish at various times after injection. Eggs may be forced from nearly ripe fish, but these eggs invariably are surrounded

by a single layer of vascularized ovarian tissue. Overripe eggs have no covering but are spotted with areas of coagulated yolk. Usually, eggs taken within 1 to 2 hr of ovulation are perfectly round, 0.7 to 0.8 mm in diameter, and have the single oil drop characteristic of this species. These eggs float in normal Salton Sea water (37 ‰) and are perfectly transparent and viable.

Fertilization of viable eggs and development to hatching was followed for random samples of eggs obtained from hormone treatments. Eggs which did not cleave were considered unfertilized. In most cases, test fertilizations were conducted in charcoal-filtered Salton Sea water, which has an ionic composition different from that of normal seawater (Carpelan, 1961). Fertilization and hatching served as final criteria of the usefulness of various preparations for spawning.

EXPERIMENTAL RESULTS

The reproductive process in fishes can be experimentally divided into four phases: (1) gonad maturation—measured as a slow increase in GSI over several weeks; (2) gonad hydration —the final preparation of reproductive products for spawning; (3) the actual spawning act—releasing eggs and sperm; and (4) fertilization and development of the eggs. These phases are interdependent and proceed in a timed sequence as part of a cycle keyed to external and internal cues which are integrated by the fish. Thus, spawning is the culmination of a whole series of events, each of which has particular physical and biological requirements for successful completion.

Although each process in the spawning cycle can be separately evaluated with appropriate experiments, it is important to keep in mind that the results must be judged against the general reproductive status of the organism. For example, the effects of hormone injections differ among croakers with different GSI's. For reasons explained in the following section, most of the experiments were focused on the reproductive processes of female croakers.

GONAD MATURATION (MALES)

Effects of Photoperiod and Temperature

Male croakers became running ripe in the laboratory under all combinations of experimental conditions. Fish of 20 to 30 g, captured in October, well beyond the normal breeding season of the species in Salton Sea, became running ripe within 3 weeks after being placed in tanks with various combinations of 14° C and 22° C water and 16L:8D or 8L:16D photoperiod schedules. Adult fish, captured at the height of the breeding season in May and June, were still ripe under all laboratory conditions in November and remained in this state until the end of the experiments in July of the following year. In the field, males become running ripe at least 1 month prior to the natural spawning season and can thus serve as indicators of the approaching breeding season in Salton Sea. They are not ripe prior to this time or after about 1 month following the spawning season, although water temperatures and day lengths are similar to those maintained in some laboratory situations in which the males did remain running ripe. It may be that either the absence of the normal Salton Sea cycle of light and temperature conditions (in which the fish experience very warm water—25°-30° C—followed by a period of winter dormancy), or the omission of the normal spawning act in the laboratory, helped to maintain the fish in running ripe condition. The threshold at which environmental factors induce spermiation may also be quite low, and in the laboratory, food, light intensity, photoperiod, and temperature acting in concert may have exceeded this level.

Effects of Hormones

Hormone injection of 1 mg salmon pituitary caused a seminal thinning response similar to that discussed by Clemens and Grant (1964). In comparison, the milt taken from uninjected fish was quite viscous and formed clots which had to be mechanically broken up to disperse the sperm. However, quantitative injections of smaller doses of salmon pituitary caused no apparent increase in the percent water of the testes (Table 1). In males, the reaction to hormones

TABLE 1.—Total weight, GSI (gonad weight/body weight × 100) and percent water in testis of male *Bairdiella icistia* injected with various dosages of salmon pituitary.

Treatment	Wet weight of fish (mean ± SD)	GSI (mean ± SD)	% water in gonad (mean ± SD)	N
Control: 0.01 ml/g sesame oil	67.96 ± 13.38	7.03 ± 1.13	85.2 ± 1.08	5
Salmon pituitary 0.005 mg/g	59.97 ± 11.67	5.25 ± 1.61	86.0 ± 1.20	5
Salmon pituitary 0.01 mg/g	59.34 ± 6.99	5.53 ± 1.74	85.8 ± 1.14	5

was not comparable to hydration in females and was not further pursued. Possibly stronger doses of pituitary would give a positive response. The time scale and extent of the seminal hydration and thinning response might be useful in assessing the effect of various hormones and dosage relationships where female fish are at a premium and males would otherwise be in excess. This bioassay technique has been used for salmon pituitary gonadotropin (Yamazaki and Donaldson, 1968a, 1968b).

GONAD MATURATION (FEMALES)

Seasonal Maturation Cycle in the Salton Sea

A series of croaker samples was taken from the Salton Sea at monthly or more frequent intervals during the year. GSI values were less than 2 % from January to mid-March 1969, prior to spawning, and less than 1 % from mid-June to December 1969, following spawning. From mid-March to mid-April, the mean GSI increased rapidly from 2 % to 10 % and reached a high of 12 % in mid-May (Fig. 1); at this time, individual females were caught with GSI's of more than 17 %. Peak spawning in the Salton Sea was observed in May and early June in 1969. Less frequent sampling and observations confirmed a similar pattern of events in 1970. In the years 1955, 1956, and 1957, Whitney (1961) found that the peak abundance of croaker eggs and larvae in the Salton Sea fell in middle and late May.

Laboratory Cycle and Effects of Photoperiod, Water Temperature, and Food

Immature fish.—Young-of-the-year croakers were captured in October 1969, placed in 14° C or 22° C water on a 16L or 8L photoperiod, and given an abundance of food (Oregon moist chow and chopped squid). These fish grew to maturity in a little less than 4 months at 16L:8D and 22° C (Table 2, group 1). Similar fish kept on 8L:16D at 14° C did not grow as rapidly as warm-water fish and did not mature under these conditions (compare groups 1 and 2, Table 2, 16-II-70). The lack of maturity was not due to the slower growth rate of the fish kept in cold water, as Salton Sea fish of lower average weight showed higher GSI values at their capture during the spawning season (Table 2, group 3). Short days, therefore, inhibited the maturation process. These same fish (Table 2, group 2) did mature rapidly, in 2 months, when the water temperature was increased to 22° C along with increased photoperiod. Young fish in their first year do not have as high a percentage of gonad as fish older than 1 year (Table 2, groups 3 and 4).

Mature fish.—A sample of fish more than 1 year old, captured in November 1968, 6 months

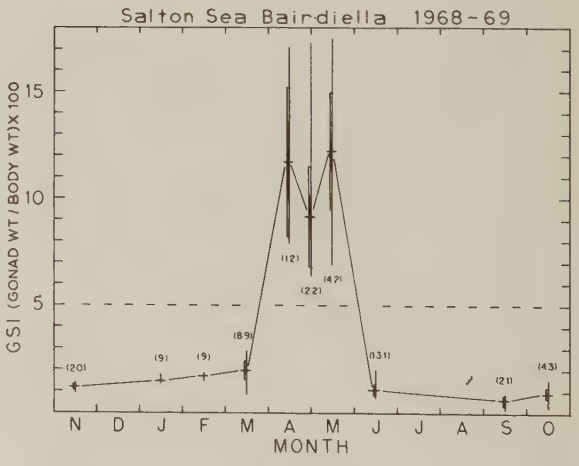


FIGURE 1.—Seasonal change in GSI of female *Bairdiella icistia* captured in the Salton Sea. Horizontal line indicates the mean GSI value; vertical line indicates range; on either side of the mean, open bar indicates the standard deviation, and closed bar two standard errors of the mean of each sample. The number of fish sampled is given in parentheses. Horizontal dashed line indicates 5 % GSI for comparison with laboratory fish (Fig. 2).

TABLE 2.—GSI values of female *Bairdiella icistia* captured in Salton Sea compared with captured fish matured in the laboratory.

Group	Date of sample	Weight (mean ± SD)	GSI (mean ± SD)	N
1	23- X -69[1]	10.47 ± 3.56	0.96 ± 0.28	9
	5-XII-69	34.30 ± 5.15	0.93 ± 0.15	11
	19-XII-69	35.40 ± 4.78	1.07 ± 0.46	10
	16- II -70	60.14 ± 11.84	5.46 ± 3.32	5
2	23- X -69[1]	10.47 ± 3.56	0.96 ± 0.28	9
	5-XII-69	31.90 ± 8.04	0.92 ± 0.14	10
	19-XII-69	33.10 ± 4.94	0.80 ± 0.09	9
	16- II -70	39.40 ± 7.16	1.28 ± 0.22	5
	4-IV-70	49.30 ± 5.01	9.69 ± 3.46	5
3	14- V-70[1]	32.38 ± 8.32	5.90 ± 3.84	25
4	14- V-70[1]	170.4 ± 84.1	7.93 ± 1.35	24
5	19-III-69	161.6 ± 22.8	10.2 ± 1.94	23

Treatments

Group 1: Laboratory stock fish sampled irregularly. All fish kept on 16L:8D photoperiod at 22° C.

Group 2: Laboratory stock separated from group 1 and maintained on 8L:16D photoperiod at 14° C until 16-II-70, when they were switched step-wise (15 min/day) to 16L:8D and 22° C.

Group 3: Young fish captured during their first breeding season in Salton Sea.

Group 4: Fish more than 1 year old, captured during the breeding season in Salton Sea.

Group 5: Fish more than 1 year old, captured following the breeding season in Salton Sea and matured early under laboratory conditions of 15L:9D and 14° to 16° C.

[1] At capture.

before their normal breeding season, reached maturity in the laboratory sometime prior to being sampled in mid-March 1969 (Table 2, group 5). These fish experienced 15L:9D and ambient La Jolla seawater temperature (14°-16° C) during 4 months in the laboratory. Cold water may slow down the maturation process, but it is evidently not as important as the stimulation of long days.

A second sample of adult fish was captured in mid-May (at the peak of the breeding season), subjected to various experimental laboratory conditions and sampled every 2 weeks to determine the status of their GSI (Fig. 2). Fish maintained on long days (16L:8D) at 14° C and 22° C showed a slow decline in GSI from a high of 12 % at capture to below 5 % by late-August and September. The GSI values at 22° C were more variable and, in general, showed a more rapid decline than those at 14° C. Similar fish given 10L:14D at high and low temperatures showed a similar but much more rapid decline in GSI, and their GSI also declined to a lower overall level (1-2 % by mid-August) than that of fish which never experienced short-day conditions.

Both groups of short-day fish subsequently showed a slow but steady increase in their GSI in response to having the photoperiod increased 15 min/day from 10L to 16L. Although this increase was not followed through a complete cycle, it was evident that exposure to long days for 2 to 3 months would have been required to bring the fish up to the GSI level necessary for spawning (about 5 %—see below).

It is likely that adult fish brought into the laboratory just prior to the normal increase in GSI observed in the Salton Sea would respond rather quickly, I estimate within 1 month, if they were given adequate light, temperature, and food. It may also be possible to mature fish rapidly after they have gone through their natural GSI decrease (Fig. 1), but this was not tested.

Effects of Hormones on Maturation of Fish Maintained in the Laboratory

Groups of fish maintained on various light and temperature regimes were subjected to hormonal treatments to enhance gonad maturation. Adult fish captured prior to the breeding season were not available for these experiments, which were conducted after the spawning season on fish undergoing a decline in GSI, as in Fig. 2. Nonetheless, the results obtained probably indicate the extent to which maturation can be influenced by hormone treatment. In croakers, the technique of hormone-induced maturation is of relatively little practical importance, since fish can be matured by appropriate manipulation of photoperiod, temperature, and feeding schedules. The results are, therefore, reported for their possible application to other species in which maturation proves more intractable.

Since the treatments were carried out on fish being used for photoperiod and temperature experiments, the results can only be evaluated in relation to the GSI value of the population under each set of conditions. In some cases, sham-injected controls were used while in others uninjected fish sampled for the light-temperature

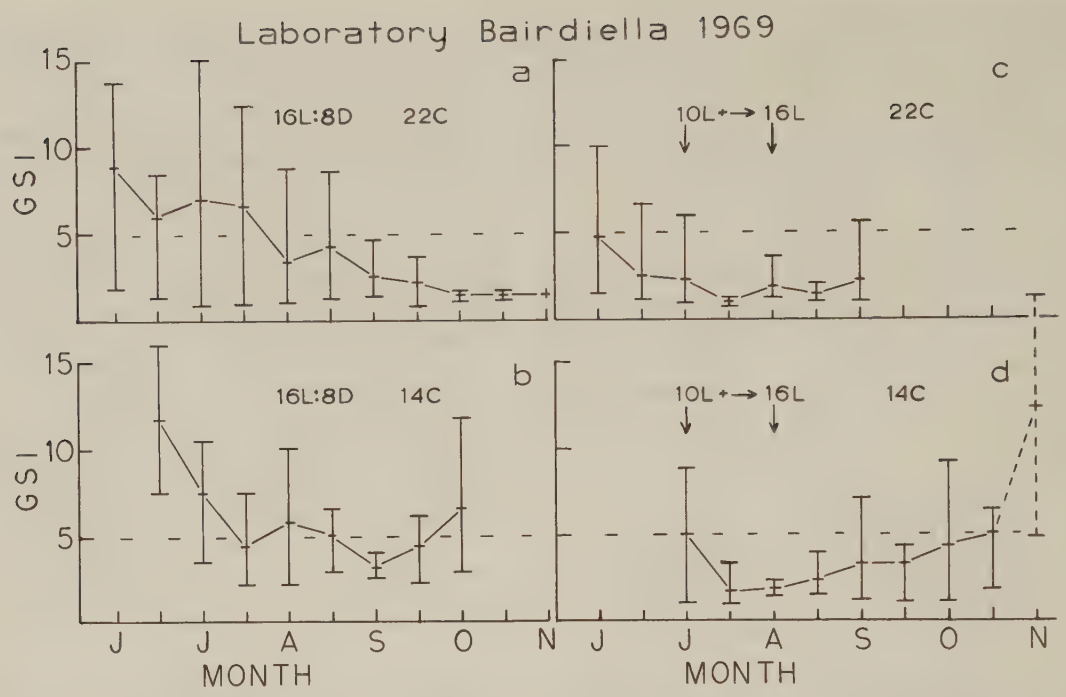


FIGURE 2.—GSI of female *Bairdiella icistia* captured during the spawning season and maintained under the following laboratory conditions: (a) 16L:8D, 22° C; (b) 16L:8D, 14° C; (c) 10L:14D, 22° C for 2 months; then, photoperiod was increased 15 min/day to 16L:8D; (d) 10L.14D, 14° C for 2 months; then, photoperiod was increased 15 min/day to 16L:8D. Mean GSI of all fish at capture (May 13, 1969) was 12.2 %. Dashed value in (d) indicates GSI of five fish injected with 1 mg of salmon pituitary 1 day prior to last sampling period. Horizontal line at 5 % GSI indicates approximate minimum level necessary for successful hormone-induced spawning.

studies served as controls when they were scheduled to be sampled at the same time as the injected fish. In all cases the gonad index responded positively to hormone treatment. Differences seen in the tabular data (Tables 3, 4, and 5) were due to the number of injections, strength and type of hormone injected, the water temperature and the GSI value of the fish at the beginning of the experiment.

In Tables 3, 4, and 5 the symbols (S, E, +, —) record the initial (2 days after the first injection) and the maximal (at some point during the series of injections) response noted for each group of fish. Two factors, water temperature and GSI, were found to have an important bearing on the results observed following hormone injection. Fish kept in 14° C water showed the most consistent and largest positive response to long-term hormone injections which were giv-

TABLE 3.—GSI of *Bairdiella icistia* given five injections, every other day for 9 days (17-26-IX-1969). Photoperiod was 16L:8D and temperature 14° C during this experiment. The response of the fish to injection was assessed every day and the maximal response is indicated by S (= spawned viable eggs), E (= obtained nonviable eggs), + (= swollen papillae observed, no eggs obtained), or — (= no observed response). The second column under each heading indicates the reproductive status of the fish 2 days after the first injection. The third column (in parentheses) indicates the maximum reaction noted during the experiment.

Treatment	1 mg salmon pituitary extract	100 IU HCG	5 mg DOCA	Uninjected control
GSI	12.4 + (E)	12.1 — (E)	11.4 — (E)	4.1 (—)
	11.6 + (E)	10.0 — (E)	6.1 — (E)	3.6 (—)
	11.1 + (E)	8.8 — (+)	5.2 — (E)	3.2 (—)
	10.9 — (—)	6.6 — (+)	4.6 — (+)	2.7 (—)
	6.0 — (+)	5.9 — (—)	male	2.7 (—)
$\bar{X} \pm SD$	10.4 ± 2.6	8.7 ± 2.5	6.8 ± 2.7	3.2 ± 0.6

TABLE 4.—GSI of *Bairdiella icistia* given six injections over a 15-day period (18-VIII-69 — 2-IX-69). Each injection consisted of 1 mg salmon pituitary extract. Fish in groups 1 and 2 experienced a 16L:8D photoperiod; groups 3 and 4 experienced 10L:14D for 2 months (to 28-VII-69) followed by day length increases to 16L:8D (by 22-VIII-69). Groups 1 and 3 were maintained at 22° C, groups 2 and 4 at 14° C throughout the experiments. Symbols (S, E, +, —) are the same as in Table 3.

	Group 1 (16L, 22° C)		Group 2 (16L, 14° C)		Group 3 (10L-16L, 22° C)		Group 4 (10L-16L, 14° C)	
	Injected	Control	Injected	Control	Injected	Control	Injected	Control
	6.5 E (E)	10.2 (—)	11.3 + (E)	10.2 (—)	5.6 — (E)	3.6 (—)	7.3 — (E)	2.4 (—)
	5.0 E (E)	3.2 (—)	9.4 + (E)	6.0 (—)	4.9 — (E)	1.6 (—)	3.3 — (+)	2.0 (—)
	4.2 + (E)	1.9 (—)	9.1 + (E)	5.5 (—)	1.8 — (+)	1.4 (—)	1.9 — (—)	1.9 (—)
	4.2 + (+)	1.3 (—)	9.1 + (E)	5.2 (—)	1.6 — (—)	1.4 (—)	1.7 — (—)	1.6 (—)
	3.6 — (—)	0.9 (—)	7.6 + (E)	2.3 (—)	1.2 — (—)	1.3 (—)	1.2 — (—)	1.4 (—)
$\bar{X} \pm SD$	4.7 ± 1.1	3.5 ± 3.8	9.4 ± 1.3	5.8 ± 2.8	3.2 ± 2.0	1.9 ± 1.0	3.1 ± 2.5	1.9 ± 0.4

TABLE 5.—GSI of *Bairdiella icistia* given three injections, one every other day for 7 days (16-IX—23-IX-1969). Photoperiod was 16L:8D and temperature 22° C during this experiment. Symbols (S, E, +, —) are the same as in Table 3.

1 mg salmon sesame oil	1 mg salmon Holtfreter's	1 mg carp sesame oil	0.1 mg salmon sesame oil	Control sesame oil
5.5 S (S)	5.0 S (S)	8.1 + (E)	6.0 — (E)	4.9 (—)
4.9 S (S)	5.0 S (S)	6.3 + (E)	3.3 — (+)	1.4 (—)
4.7 — (E)	4.6 — (E)	2.7 — (E)	3.0 — (+)	1.4 (—)
4.1 — (E)	3.6 — (E)	2.7 — (+)	2.5 — (+)	1.1 (—)
1.8 — (—)	1.4 — (—)	2.5 — (+)	1.5 — (—)	1.0 (—)
$\bar{X} \pm SD$ 4.2 ± 1.4	3.9 ± 1.5	4.5 ± 2.6	3.2 ± 1.7	2.0 ± 1.6

en every other day for 1 to 2 weeks (Table 3; Table 4, groups 2 and 4). Fish in 22° C water also showed a positive response (Table 4, groups 1 and 3; Table 5); however, this response is less clear because warm-water fish occasionally shed their eggs prior to sampling and this reduced the observed GSI.

In general, fish with GSI values below 5 % did not respond to the first injection (—), responded with a weak swelling in the genital area (+), or gave nonviable eggs (E) only after several injections. This indicated that threshold values of GSI and temperature exist below which "growth" and above which hydration and ovulation occur in response to hormone injections. These values will be further discussed in the section on ovulation. Here it will suffice to point out that hormone treatment does give rise to increases in gonad size which can perhaps be considered the equivalent of gonad growth.

The tabular data indicate that salmon pituitary caused the greatest increase in GSI of fish kept in cold water. Salmon was followed by HCG and then DOCA (Table 3). Salmon pituitary produced smaller increases in warm water than in cold (Tables 3, 4, and 5), and the response tended to vary in proportion to the dosage used (Table 5). The relatively small response at 22° C in Table 5 was probably due in part to the lesser number of injections (3) in this batch and in part to the fact that three of the fish spawned relatively large quantities of eggs (see qualitative responses in Table 5), thus reducing their GSI values, which were measured after testing for the presence of viable eggs. However, the results of the longest series of injections (Table 4) suggest that there is a general pattern of greater increase in GSI in cold water, except in the case of fish with a very low initial GSI.

In warm water (Table 4, group 1; Table 5), fish produced viable eggs (S) or nonviable eggs (E) which could be forced out the day after the first injection. Cold-water fish (Table 3; Table 4, groups 2 and 4) required several injections to produce a response and never spawned viable eggs on stripping.

In a further experiment, young-of-the-year fish collected in October were injected shortly thereafter with various concentrations of salmon pituitary to assess usefulness of immatures as a bioassay in testing dose-response relationships. Each fish received five injections over a 10-day period. At each dose level a large number of fish (20) was injected, but, because of the difficulty in identifying the sex of these immature fish, the number of females actually injected was somewhat smaller. Also, the gonads were quite small, and the overall GSI response was slight. This made any meaningful analysis difficult. How-

TABLE 6.—GSI of young female *Bairdiella icistia* after five injections of various concentrations of salmon pituitary extract over a 10-day experimental period (4-XI-14-XI-69).

Dose	Weight (g) mean ± SD	GSI mean ± SD	N
Control sesame oil	26.07 ± 5.78	0.79 ± 0.08	13
0.1 mg salmon	23.90 ± 6.23	0.82 ± 0.22	10
0.5 mg salmon	28.40 ± 4.46	0.88 ± 0.18	13
1.0 mg salmon	26.97 ± 6.88	0.99 ± 0.19	17

ever, the results (Table 6) do indicate a general increase in GSI corresponding to dose. That these fish were not too small to respond to treatment is indicated by the high GSI observed in similar sized fish captured in Salton Sea during the breeding season (Table 2, group 3). It is possible that the rather small response observed was due in part to the fact that the fish were handled frequently and did not feed readily during the course of the experiment. This test would probably be more successful if carried out with 30- to 50-g fish kept under short-day conditions at 14° C.

GONAD HYDRATION

Water Uptake Following Hormone Injections

Weight gain on various hormones.—Short term changes in body weight occurred 1 to 2 days following the injection of various hormones. This weight change was recorded as a percent of the initial total body weight (Table 7) and was found to vary from slightly negative values to positive values of over 13 % of the body weight. Single injections were given, and fish were weighed prior to, and 30 hr after, injection. With few exceptions, the fish showed little or

TABLE 7.—Effects of hormones of GSI of *Bairdiella icistia* at 30 hr post-injection. (1 = did, 0 = did not hydrate or ovulate.)

Preparation, dose, and date	Initial body weight (g)	Weight change (% initial weight)	GSI (% final weight)	Hydrate	Ovulate
Carp pituitary 10 mg					
10-VI-70	51.07	+10.99	9.34	1	0
	70.46	+5.42	19.80	1	0
	72.79	+11.72	25.50	1	0
	57.22	+12.82	28.60	1	0
Carp pituitary 5 mg					
16-VI-70	71.40	--	5.42	0	0
	54.22	--	8.14	0	0
Salmon pituitary					
0.1 mg, 5-VI-70	48.33	−0.93	2.88	0	0
	55.90	−2.45	3.60	0	0
	49.40	+2.39	10.97	(1)	0
	66.14	+0.06	12.41	0	0
Salmon pituitary					
0.5 mg, 2-VI-70	65.18	−2.59	3.83	0	0
	62.77	−1.96	5.02	0	0
	74.83	−0.64	5.18	0	0
	56.22	+8.75	21.76	1	1
Salmon pituitary 1 mg					
28-IV-70	96.12	+9.40	15.90	1	1
15-V-70	65.50	+13.40	--	1	1
18-V-70	79.90	+13.10	--	1	1
15-V-70	131.20	+6.00	--	1	1
Salmon pituitary 2 mg					
10-IV-70	93.30	--	24.47	1	1
23-III-70	68.92	--	25.67	1	1
10-IV-70	100.03	--	28.08	1	1
Salmon pituitary 5 mg					
28-V-70	66.1	+7.35	20.79	1	0 (few eggs)
	65.4	+6.11	21.23	1	0 (few eggs)
Salmon pituitary 5 mg—Con.					
	91.7	+10.09	25.94	1	1 (poor eggs)
	62.3	+8.06	26.64	1	0 (few eggs)
PMS 100 IU					
27-IV-70	86.8	--	21.00	0 (?)	1
	--	--	--	0 (?)	1
12-V-70	88.7	+4.18	--	1	1
7-V-70	173.6	+11.98	24.02	1	0
PMS 50 IU					
9-VI-70	80.38	−3.06	2.90	0	0
	54.89	+4.10	14.60	1	1
	69.90	+7.77	18.50	1	1
	62.18	+12.06	24.10	1	1
HCG 100 IU					
28-IV-70	68.5	--	28.76	1	0
14-IV-70	87.5	--	29.37	1	0
15-IV-70	84.5	--	30.29	1	0
HCG 50 IU					
16-VI-70	78.51	−2.09	2.69	0	0
	57.03	−1.95	3.65	0	0
	67.91	−1.29	3.68	0	0
	80.41	+7.15	19.80	1	1
Oxytocin 20 IU					
18-VI-70	59.12	−0.70	1.60	0	0
	65.66	−1.02	3.37	0	0
	72.11	−0.11	3.95	0	0
	60.08	+2.39	11.97	1	0
DOCA 5 mg					
15-VI-70	54.78	−0.51	4.07	0	0
	53.70	−3.07	4.28	0	0
	55.33	−0.55	7.98	0	0
	73.10	−1.20	9.78	0	0

no response to 0.1 and 0.5 mg salmon pituitary, 5 mg carp pituitary, 50 IU HCG, 20 IU oxytocin, and 5 mg DOCA. On the other hand, 1 to 5 mg salmon, 10 mg carp, and 100 IU HCG, gave uniformly positive results, all fish showing weight gains of 5 to 13 %. Variable results were observed with 50 and 100 IU PMS. Although most PMS fish which were weighed showed some gain in weight, this was in general less than that observed with carp, salmon, and HCG. In fact, it was noted that two fish injected with 100 IU PMS spawned freely without ever appearing grossly bloated, a characteristic of all fish which were spawned with other preparations.

The time scale of weight gain.—A comparison was made of the weight gained by fish given one injection of 5 mg salmon, 10 mg carp, and 50 IU PMS (Table 8). The time span of hydration was arbitrarily divided into the weight gained between 7 and 23 hr post-injection and the total weight gained, including that added between 23 and 30 hr. At 30 hr ovulated eggs, if present, were stripped from the fish. Generally, all fish lost weight in the first 7 hr, probably because of handling and lack of feeding during the experiment. The weight gains are due mostly to water uptake and movement of water into the gonad.

TABLE 8.—Effects of hormones on time-course of weight gain.

Preparation and dose	Initial fish weight	Percent weight gain	
		7-23 hr post-injection	7-30 hr post-injection
	G	%	%
Salmon pituitary 5 mg	66.1	4.58	7.35
	91.7	7.72	10.09
	65.4	4.59	6.11
	62.3	4.41	8.46
Carp pituitary 10 mg	57.22	7.38	13.13
	51.07	4.17	10.44
	72.79	6.76	13.11
PMS 50 IU	54.89	0.13	5.25
	62.18	4.86	13.11
	69.9	2.88	9.69

The results show that the weight increase in the final 7 hr prior to spawning is less than 50 % of the total increase with salmon pituitary, more than 50 % with PMS, and about equal when carp pituitary is used. This evidently reflects some fundamental difference in the way these preparations affect the physiological mechanism causing hydration. The time-course of hydration (Table 8) may be important in determining the condition of eggs at ovulation (Table 7). It should be noted that among the three groups tested for the time-course of hydration, viable eggs were obtained only from the PMS-injected fish (Table 7); unfortunately, there is no comparable data on the time-course of weight gain in fish given 1 mg salmon, which also produces viable eggs.

Factors Affecting Hydration

GSI.—It is apparent from Table 7 that the gonad must be close to 5 % of the body weight to respond to an otherwise adequate dose of hormone. Although GSI could not be measured prior to injection, almost all fish which failed to respond had final GSI's below 5 %. Table 9 presents further confirmation of this. These fish, injected with 1 mg salmon, came from a stock which had shown a general decline in GSI, because of being kept on a long photoperiod for an extended time. Of four injected fish, three hydrated and one of these subsequently spawned. The fish that neither hydrated nor spawned had a final GSI of just under 3 %. Only 1 of 11 uninjected fish from this same stock showed a GSI above 5 %, while 3 more were above 4 %.

TABLE 9.—GSI of *Bairdiella icistia* measured on 26-VI-70.

A. Fish injected with 1 mg salmon pituitary, after GSI had declined (1 = did, 0 = did not hydrate or ovulate).

Initial body weight	Weight change (% initial weight)	GSI (% final weight)	Hydrate	Ovulate
53.10	+14.73	24.42	1	1
65.38	+7.40	10.55	1	0
60.14	+4.21	6.94	1	0
79.89	−2.21	2.77	0	0

B. Uninjected fish from same tank.

Total weight	GSI
67.65	1.63
53.20	1.79
93.28	0.05
58.86	4.38
63.48	1.27
61.90	4.57
78.60	1.70
74.70	2.08
53.24	2.59
69.29	7.86
59.46	4.80

Hormone dosage.—In general, there appears to be a threshold response to dosage. Fish with high GSI values and between 50- and 100-g body weight hydrated after one injection of 10 mg carp but not 5 mg (Table 7). With salmon, 1 to 5 mg were adequate doses for 50- to 350-g fish while 0.1 and 0.5 mg were inadequate except in one case. In the case of HCG, 100 IU caused hydration while 50 IU did not except in a single case. Note, however, the low GSI value measured for three of the fish given 50 IU HCG.

It must be noted that the highest dosages used were adequate for hydration but inhibited spawning (see section following on ovulation). This was true for 10 mg carp, 5 mg salmon and, especially, 100 IU HCG where the fish continued to gain weight and eventually died in the tank without ovulating a single egg. These results would suggest that it is important to determine the lowest possible dosage which will consistently bring about hydration.

Temperature.—A temperature threshold underlies the entire spawning process. Between 14° and 17° C the fish did not hydrate in response to an otherwise adequate dosage of 1 mg salmon pituitary. Two days later these same fish spawned within 30 hr when given a second 1-mg-salmon injection 24 hr after being transferred to 22° C water.

OVULATION

Ovulation and Hydration as Separate Events

Some early results with 100-IU-PMS and 100-IU-HCG injections led to speculation that the two hormones were acting on different physiological processes. PMS brought about ovulation without gross hydration while HCG hydrated fish to the point of death without ovulation (Table 7). This result was not confirmed with 50-IU doses, but, in general, the impression gained was that PMS produced high quality eggs with less hydration than either HCG or salmon pituitary.

In sharp contrast to the PMS results, HCG caused uniform hydration but, with one exception, failed to bring about ovulation. In a preliminary test, it was found that oxytocin (20 IU) or salmon (1 mg) caused some eggs to be ovulated when the injection was given 24 hr after the fish were injected with HCG. Oxytocin and salmon pituitary had the same effect on carp-injected fish which otherwise did not ovulate.

Ovulation without apparent hydration was also achieved by using multiple, subthreshold doses of 0.1 and 0.5 mg salmon pituitary, but the time of ovulation could not be accurately predicted, and therefore the eggs obtained usually were not viable. (The importance of obtaining eggs just at ovulation is discussed in the section on fertilization.)

In summary, carp pituitary, HCG, DOCA, and oxytocin were uniformly inadequate for bringing on ovulation except in the case of one fish treated with HCG. Both carp- and HCG-injected fish hydrated, some becoming grossly distorted. On the other hand, salmon pituitary and PMS regularly brought about ovulation. Dosage appeared to be critical in the case of salmon pituitary, as nonviable eggs resulted from injections of 5 mg and no spawn could be obtained with a single dose of 0.1 and 0.5 mg. A 1-mg-salmon dosage seems to be optimal for fish of 50- to 100-g total weight. Both 50- and 100-IU dosages of PMS gave good results with remarkably clear eggs obtained from all fish. In one case, a 50-IU dose of HCG was adequate for spawning, but 100 IU appeared to be inhibitory to ovulation.

The Time Scale of Ovulation

The combined results from 28 fish which produced viable eggs following injection with a single dose of salmon (1-3 mg) showed that the average time elapsed from injection to spawning was 30.4 hr, with a standard deviation of 3.3 hr and a range of 24.5 to 35.5 hr (Fig. 3). This 30-hr latent period following injection generally held regardless of the type of hormone used, its dosage, or the time of day the injection was made. In the case of a few large fish (100 to 300 g) given 1 mg salmon, a second 1-mg injection was given 24 hr later, but this did not affect the time of spawning. Five fish given 5 mg salmon spawned 28 hr after injection, but their eggs were not viable. In one experiment,

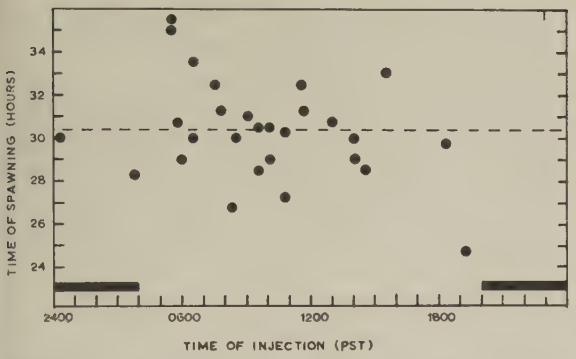


FIGURE 3.—Time of injection (Pacific Standard Time) and time of spawning (hours post-injection) in relation to photoperiod. All injections were 1-3 mg salmon pituitary extract and all fish produced viable eggs. Solid black bar indicates dark period; dashed line indicates mean time of spawning.

five fish were injected with 1 mg salmon at a time corresponding with the beginning of the laboratory dark cycle. All these fish spawned 24 hr later, indicating a possible enhancement by the normal diurnal cycle of glandular activity. Natural spawning in the Salton Sea is related to the normal diurnal light cycle, with most spawning occurring in the early evening.

Factors Affecting Ovulation

It has already been shown that GSI level, hormone dosage and type of hormone are critical interacting factors which must be considered in any spawning effort. Injection of high levels of salmon (5 mg) may possibly assure a more uniform hydration response (see GSI of Table 7), but the nonviable eggs which result speak against using more than the minimal dose found to give consistent results.

The effect of temperature on ovulation per se was not studied. Hydration is effectively blocked at temperatures lower than 17° C, but this effect was reversed after 24 hr acclimation at 22° C. In the cases in which this transfer was carried out, a second injection was given 24 hr after transfer, and spawning took place approximately 30 hr later.

As a matter of practical interest, it was found that fish could be injected and spawned twice (tried, successfully, with two fish) or three times (one fish) with a period between spawnings of 3 to 4 weeks. This is in contrast to the much longer time required for maturation after fish had slowly resorbed their gonads in photoperiod experiments (Fig. 2). Apparently the rapid emptying of the gonad consequent upon hormonal injection quickly leads to a renewed cycle of egg maturation.

The direct and indirect effects of various injections on the gonad were assessed by biopsy following spawning or the lack of spawning. These qualitative observations are listed in Table 10; no attempt is made to interpret these results, except to point out that fish injected with salmon pituitary extract had gonads most closely resembling those of naturally spawning fish.

TABLE 10.—Appearance of mature *Bairdiella icistia* ovaries during natural spawning and 30 hr after various hormone injections, and color reaction of fish to injections.

1. Salton Sea fish at spawning
   Gonad color white, light yellow or red-orange. Consistency of mature gonad is granular with patches of transparent eggs which are close to being ovulated or are lying free in the ovarian lumen.
2. Salmon pituitary extract
   Gonad color and consistency very close to naturally spawning fish. Most eggs ovulated and free in lumen. Fish blanch on injection.
3. Carp pituitary extract
   Gonad color red-orange; few eggs ovulated. In fish given 5 mg dose, blood clots appeared to be blocking oviducts near vent. Fish blanch on injection.
4. PMS
   Gonad whitish, translucent; strikingly different from other preparations. Most eggs ovulated and free in lumen. Possibly, greater degree of ovulation with less hydration makes gonad appear lighter in color. Fish do not blanch on injection.
5. HCG
   Eggs either not ovulated or partially ovulated; those not ovulated appear as white patches in the ovary. Many vacuoles and dispersed oil drops appear in eggs. Fish do not blanch on injection.
6. Oxytocin
   Ovary was very bloody. Eggs white (not hydrated); different sized eggs (mostly large) apparent in ovarian folds. Fish do not blanch on injection.
7. DOCA
   Fish showed no observable reaction.

FERTILIZATION

Relationship of Egg Viability to the Time of Ovulation

Shortly before ovulation, eggs could be squeezed from females by applying strong pressure to the abdomen, but eggs obtained in this way still had an investiture of blood vessels and ovarian tissue and could not be fertilized. An analysis of viability in relation to the time after

TABLE 11.—Fertilization and viability of *Bairdiella icistia* eggs tested over a 4-hr period following first ovulation. Fish was injected with 1 mg salmon pituitary extract at 0930 1-V-70; first eggs expressed with some difficulty at 1530 2-V-70.

Time of fertilization	Fertilization	Development to early tailbud	Hatching
	%	%	%
1530 hr (not quite running ripe)	100	91	84
1630 hr (running ripe)	100	91	83
1730 hr	100	78	72
1830 hr	90	62	44
1930 hr (eggs spotty, opaque)	5	52	34

ovulation was made in the case of one fish which remained ripe for 4 hr (Table 11). To check for viability, eggs were test-fertilized at hourly intervals following the first sign of ovulation, taken as the earliest time when normal eggs could easily be expressed from the fish by gentle pressure applied to the abdomen. Fertilization and early cleavage remained above 90 % up to 3 hr post-ovulation. By 4 hr the eggs looked crinkled, opaque, and spotty, and less than 5 % could be fertilized. A further measure of viability was made by culturing 100 early cleaving eggs from each batch until hatching. A decrease in hatching success was noted in the eggs obtained 2 hr after the initial ovulation, and hatching decreased still further in the 3- and 4-hr post-ovulatory samples. It appears that the maximum grace period for egg-taking is about 2 hr. In another experiment I studied eggs from a larger sample of 10 fish determining fertilization success as a function of time after ovulation; the optimum time for taking eggs was 1 hr after the fish first showed signs of running ripeness and gave viable eggs.

Although eggs rapidly deteriorated when kept in the ovary following hormone-induced ovulation, it was found that they retained their ability to be fertilized up to several hours after they were placed in a moist storage chamber. Eggs placed in seawater remained fertile for several minutes; in one case, a few cleaving eggs resulted from fertilization carried out after the eggs had been in seawater for 30 min.

Viability of Sperm

Although eggs kept in seawater remained viable for several minutes, sperm were no longer able to fertilize eggs 30 sec after the sperm mass had been introduced into seawater. It is thus readily apparent that croaker sperm and eggs should be mixed immediately after the sperm is obtained, in order to achieve maximum fertilization. Microscopic examination showed that sperm were immediately activated by addition of water and retained motility for a period of 1-5 min. In some tests it was apparent that water from the Salton Sea caused greater activity for a longer time than water taken from the ocean at La Jolla, Calif., but there was great variability between males, and a proper technique of quantifying this relationship awaits further studies.

Number of Eggs Obtained by Hormone Treatment

The number of eggs obtained by hormone injection varied between 700 and 1,000 per gram of fish wet weight (Table 12). This provided 50,000 to 100,000 eggs for experiments from each fish of 50 to 100 g used in this study.

TABLE 12.—Number of eggs obtained from hormone-induced spawning of *Bairdiella icistia*.

Wet weight		GSI	Ripe eggs		Actual count (1 g eggs)	Eggs/g fish weight	Approximate total eggs/ fish
Total fish	gonad		Body weight	Gonad weight			
G	G		%	%			
82.0	17.7	21.6	16.0	74.0	4,700	841	69,000
86.6	17.6	20.3	15.5	78.1	--	[1]793	[1]69,000
91.7	26.0	25.9	19.7	76.1	5,590	1,101	101,000
342.7	62.1	--	--	75.0	--	[1]699	[1]240,000
441.5	129.7	--	17.1	--	--	[1]878	[1]388,000

[1] Indicates values calculated from measured parameter and mean number of eggs per gram counted.

DISCUSSION

MATURATION

Many experiments have shown that gonad maturation can result from hormone therapy (for reviews see Pickford and Atz, 1957; Ahsan and Hoar, 1963; Atz and Pickford, 1964; and Hoar, 1969), but in most cases this is a long and tedious approach and has proved of practical use only on a short-term basis for elucidating mechanisms of hormone action. A recently described catheter implant technique (Frogner and Hendrickson, 1970), allowing frequent or continuous administration of hormones, has been used with partial success to mature mullet, *Mugil cephalus*, with a minimum of damage from excessive handling (Shehadeh, personal communication). A mass of tangled catheters is envisioned if this technique were applied to commercial fish production, but the ease of this method may have considerable merit for experimental situations. Implanted pituitary glands might also be used to enhance maturation, and this could easily be tested in croakers.

In the present study, a slight increase in GSI, possibly reflecting enhanced gonad "growth," followed 1 to 2 weeks of hormone injections given every other day to fish held in 22° C water. Even greater "growth" enhancement was observed in 14° C water, and these fish could have been spawned using techniques which were fully developed later in the study. However, for practical purposes, it proved simpler to mature croakers in large groups using appropriate schedules of long days, warm water, and abundant feeding.

The fact that fish kept in cold water respond to hormones by gonad enlargement without subsequent hydration or ovulation indicates that different temperature thresholds exist for these various processes. It is possible that the rate of absorption of hormone is considerably slowed in cold water, as some fish do develop a slight reaction following several days of injection at 14° C.

The general relationship of light and temperature to gonad maturation is well known (see Harrington, 1959; Henderson, 1963; Wiebe, 1968; and Hoar, 1969, for reviews) and requires no lengthy discussion here. It is sufficient to note that long-day photoperiod (16L:8D) and high temperature water (22° C) induce gonad maturation in croakers several months prior to the normal breeding season observed in the Salton Sea. Also, a combination of long days and low temperature (14° C) will retard the normal GSI decline when the fish have been captured at the peak of breeding. This technique may prove useful for maintaining fish in a mature state for prolonged periods; such fish may be subsequently spawned following transfer to warm water (22° C) for a period of 1 day.

Studies on the relationship between maturity and spawning indicate the existence of a GSI threshold value of about 5 %, below which hormone injections are ineffective. Also, fish brought to maturity with photoperiod and temperature control eventually resorb gonadal tissues if they are not subsequently spawned. This resorption process requires several weeks, and the gonad will not grow in response to photoperiod and temperature during this time. Fish which are spawned with hormones do not show a refractory state and can be respawned within a few weeks. The practical implication of these findings is that the GSI of maturing fish should be frequently checked so that spawning can begin soon after the 5 % GSI threshold is reached and the fish should be spawned before they reach the maximum GSI value and begin gonad resorption. A useful approach would be to hold stock supplies of fish on short days at low temperature and mature separate groups as needed for experiments.

Samples of croakers taken throughout the year from Salton Sea showed that maturation is quite rapid, the GSI increasing from 2 to 10 % in a little over 1 month. It is probable that the increased light, temperature, and food stimulation available in the laboratory could bring about even more rapid maturation, but the proper fish (early spring) to test this were not obtained during this study.

HYDRATION

Hormone-induced gonadal hydration is a relatively rapid phenomenon which is completed

in a little over 1 day following injection under laboratory conditions. In croakers, the total water uptake is reflected primarily in increased gonad weight and may amount to more than a 10 % increase in total body weight. A detailed study of the gonadal hydration of carp, *Cyprinus carpio*, and goldfish, *Carassius auratus*, following injections of carp pituitary extracts showed a similar pattern of water movement into the gonad with respect to time (Clemens and Grant, 1964). These authors measured the increased water content of the gonad following injection and found that, in the case of males, the peak of seminal fluidity was 24 hr after a single ip injection. A similar response was observed with im injection. Goldfish females injected with 10 mg/g carp pituitary extract showed similar responses, increasing gonad water by up to 7.2 % over carrier-injected controls. Unfortunately, the changes they describe are in the relative water content of gonads and various other tissues including blood, and no mention is made of any increase in total body weight resulting from water taken up from the external medium.

Hydration under laboratory conditions results in a grossly distorted appearance in females, the abdominal cavity becoming bloated several hours prior to spawning. In the Salton Sea, females appear plump but never grossly enlarged at spawning. It is possible that naturally spawning females hydrate and ovulate frequently but in small amounts over the course of the breeding season and that the laboratory fish show the maximum hydration and ovulatory response because of unnatural overstimulation with the injection of salmon pituitary. Use of 10 mg carp pituitary and 100 IU HCG caused an equally strong hydration response, but generally this did not culminate in ovulation when these preparations were used alone. A dose threshold for response was indicated by the inability of 1 to 5 mg of carp pituitary to cause hydration. With 100 IU HCG, continued hydration without ovulation evidently overstressed the fish and led to their eventual death. On the contrary, PMS gave somewhat variable results, but appeared to have less effect on gonad hydration while, at the same time, proving to be a potent ovulating agent. Subthreshold doses of salmon pituitary do not appear to cause hydration, but a sequence of injections given at daily intervals will eventually lead to ovulation of small quantities of eggs. This may reflect the response of exceptionally ripe eggs which are able to hydrate and ovulate.

Thresholds of GSI (above 5 %), water temperature (between 17° and 22° C), and hormone dose (e.g., 1 mg or more of salmon pituitary for 50- to 100-g fish) exist, and if any one of these factors is below its threshold, hydration does not occur.

OVULATION

Ovulation in croakers is a rapid process, taking 1 to 2 hr for completion when induced with hormones in the laboratory. The period between injection and spawning includes the hydration phase and culminates in ovulation at about 30 hr post-injection. Stevens (1966) found a similar 30-hr latent period for fully mature striped bass, *Roccus saxatilis*. Clemens and Sneed (1962) found a shorter latent period of 15 hr for goldfish. Fontenele (1955) gave injections to several Brazilian fish species at 6-hr intervals. He stated that spawning usually occurred just prior to the 5th injection (i.e., close to 30 hr after the first injection), although in most cases the fish were allowed to spawn naturally in ponds and were not tested by stripping. Indian carp are also allowed to spawn naturally in ponds after injection. Chaudhuri (1960) states that spawning may come 6 to 8 hr after the first injection of very mature fish; if a second injection is necessary, the total elapsed time may be 14 to 18 hr. It would appear that in most recorded cases (see above and Pickford and Atz, 1957, Table 46) hormone injection will bring about final maturation and spawning within 1 to 2 days if the gonads are fully mature. In only a few cases (e.g., Joseph and Saksena, 1966) have longer series of injections been successfully used to produce viable eggs.

A constant time period for spawning latency was found to hold for croakers used in this study. When GSI, water temperature, and hor-

mone dosage all exceed certain threshold levels, the fish spawned viable eggs an average of 30 hr after the first injection. Hormone dosages above threshold and the type of preparation had no apparent effect on this result, which exhibited only small variability. Subthreshold doses of salmon pituitary did delay ovulation, but this delay could not be accurately predicted, and therefore the spawn obtained was never viable. Subthreshold doses might theoretically be useful if females were to spawn naturally in captivity, but croakers never exhibited complete spawning behavior in tanks following hormonal injections. Injection of oxytocin in hydrated females and in males appeared to cause heightened prespawning behavior, with males following and touching the vent of females, but actual spawning was not observed. Hydrated females eventually expelled their eggs into the tanks if they were not hand-stripped shortly after ovulation. Actually, the relatively constant latency and the fact that fish must be hand-stripped are highly advantageous to scheduling laboratory operations.

At Salton Sea, eggs of gulf croakers sampled from the plankton and staged at various times during the day and night showed that there is a diurnal pattern of spawning, most early cleavage stages appearing in the early evening (Whitney, 1961). The same diurnal pattern was found in a closely related species from the East Coast, *B. chrysura* (Kuntz, 1914). When the effect of this diurnal pattern on laboratory spawning was tested by injecting fish at a time corresponding to the beginning of the laboratory dark cycle, all five injected fish spawned just at "dusk," 24 hr after injection rather than the usual 30 hr. However, such enhancement was not found in any subsequent spawning attempts carried out at many different times of day and night. Clemens and Sneed (1962) found no change in latency in goldfish, groups of which were injected at 2-hr intervals over a period of 12 hr. Evidently, the injection of hormones usually overrides any effect of diurnal spawning patterns.

Clemens and Sneed (1962) found that the latent period decreased with increasing temperature, doubling from 12 hr at 30° C to 25 hr at 10° C. Croakers spawn above 20° C in the Salton Sea, and eggs develop to hatching between 20° and 30° C in the laboratory (Robert C. May, Scripps Institution of Oceanography, personal communication). However, all laboratory spawning was accomplished at 20° to 22° C, and no tests were run to determine if higher temperatures would decrease the latent period. At temperatures below 17° C, the croaker does not hydrate or ovulate in response to hormone injection.

For 50- to 100-g croakers, with GSI levels above 4 to 5 %, a single injection of 50 IU PMS, 50 IU HCG, or 1 mg salmon pituitary proved adequate to induce spawning. A dosage of 100 IU PMS and 2-3 mg salmon also produced viable eggs, but 5 mg salmon produced nonviable eggs in the four fish tested. A single injection of 10 mg (not 5 mg) carp pituitary or 100 IU HCG was adequate for hydration but not for ovulation.

An injection of 20 IU oxytocin or 5 mg DOCA apparently had little or no effect on hydration, although DOCA may have caused some slight change in the GSI.

Oxytocin may affect spawning directly. Liley (1969) reviews evidence that the spawning reflex is controlled by behavioral stimulation of the CNS which releases oxytocin. Oxytocin is used up during the reproductive season of fishes, e.g., *Fundulus* and *Oncorhynchus* (Perks, 1969).

The possibility that a second hormone, acting (in concert or independently) directly on ovulation, was absent from HCG or in too low a concentration in carp pituitary was evaluated in a preliminary way by injecting 10 mg carp or 100 IU HCG fish with 20 IU oxytocin at 30 hr or an otherwise inadequate dose (0.1 mg) of salmon 24 hr after the initial injection. Evidence was obtained for ovulation shortly after injection (oxytocin) or at 30 hr (salmon), although the eggs usually were not viable. These experiences indicated that hydration alone was not sufficient to initiate ovulation and that the latter may be a separately controlled process.

The apparent contrast observed with respect to the different abilities of HCG and PMS to hydrate and ovulate fish may possibly be

interpreted as additional evidence that a two-hormone system exists for reproductive control in fishes similar to the FSH-LH system of birds and mammals (see Ahsan and Hoar, 1963; Hyder, 1970, for details). HCG is LH-like while PMS is FSH-like; fish pituitary extracts show strong LH and slight FSH activity in mammals,, but there is a great deal of conflicting evidence and interpretation (Sundararaj and Goswami, 1966; Hoar, 1969). Other evidence indicates that PMS acts like a combination of FSH and LH when tested in mammals (Ball, 1960), but this effect can be modified by the dosage used. Hoar (1969) presently considers it likely that teleost pituitaries contain only a single gonadotropin.

Sundararaj and Goswami (1966) demonstrate how wide the range of conflicting results can be, when they report that hypophysectomized catfish, *Heteropneustes fossilis*, spawned ripe eggs after injection with appropriate concentrations of LH, HCG, PMS, and DOCA, while FSH brought about ripening but no spawning (LH contamination was possible). PMS did cause ovulation in striped bass (Stevens, 1966). HCG has been used successfully in other fish spawning studies (e.g., Sneed and Clemens, 1959; Stevens, 1966). The fact that both PMS and HCG can lead to successful spawning and, yet, reflect basically antagonistic systems in mammals should make these hormones prime targets in future experiments.

It is quite evident that considerable work remains to be done to untangle the connections between hydration and ovulation, which are certainly related events, but may be controlled by different hormones acting at different threshold levels.

The puzzling fact that one out of four 50 IU HCG fish hydrated and spawned while three out of three 100 IU fish hydrated but never spawned, might be explained by postulating that a "critical dose" exists, with doses above or below this level being unable to induce the complete sequence of spawning events. The three 50 IU fish which did not hydrate would perhaps have spawned if their GSI had been above 5 %. A "critical dose" phenomenon might also be involved in the observed difference in hydration and the complete lack of spawning obtained with 5 mg and 10 mg carp pituitary, as both groups showed GSI values above 5 %; in this case the "critical dose" might lie between 5 mg and 10 mg.

Carp is considered a universal donor by Clemens and Sneed (1962) and was successfully used to spawn several species of freshwater fishes. Bioassay with goldfish showed 100 IU HCG to be equivalent to 0.5 mg acetone-dried carp pituitary (Sneed and Clemens, 1959), and ovulation was obtained with 100-1600 IU HCG and 0.5-3.0 mg carp. Most other workers also report no inhibition of spawning from very large doses, but they all point out the critical nature of exceeding some lower threshold dose to initiate ovulation. The strength of pituitary extracts for spawning is assumed to be related to the reproductive status of the donors, a datum not given by the company selling the carp pituitaries used in the present experiments. Salmon pituitaries, however, were removed only from fish graded at the hatchery for optimal ripeness and the glands were taken within 15 min of death. Nonetheless, from the results of this study 1 mg of salmon pituitary appears to be 5 to 10 times more potent than 1 mg carp and about equal to 50 IU HCG or PMS, although definite qualitative differences in response exist. A truly valid comparison of the strength of various fish pituitary preparations can of course be made only by standardized bioassay (for reviews of methods see Clemens and Sneed, 1962; Das and Kahn, 1962; and Yamazaki and Donaldson, 1968a and 1968b).

It is clear that the effects of hormones vary with the GSI level of the experimental fish. Most of these spawning experiments were carried out over a 2-month period beginning in mid-April and ending in mid-June, while the GSI was gradually decreasing in the stock of fish used for the experiments. Thus, it is difficult to directly compare the effects of 50 IU and 100 IU HCG, as they were tested almost 2 months apart and the average GSI values of the experimental fish may have been somewhat different. The effect of the population's declining GSI is clear in the

case of a standard 1 mg dose of salmon pituitary, which caused hydration, but produced eggs from only one fish in the last test (late June 1970) carried out with the same stock of fish which had been spawned regularly with the same dose over the prior 2 months.

FERTILIZATION

Several early attempts to fertilize gulf croaker eggs all ended in failure. These eggs were obtained from hormone-induced spawning, and they appeared normal in all respects; however, the sperm mass was dispersed in the water some time prior to adding the eggs. Later studies showed that no fertilization resulted when the sperm and eggs were mixed more than 30 sec after sperm had been placed in water, while eggs retained their ability to be fertilized for several minutes when kept in water and for several hours when stored in moist chambers. The early failures to fertilize eggs thus resulted from not utilizing diluted sperm quickly enough. It is well known that sperm may be stored for long periods of time if it is maintained in concentrated form or is not activated by the diluent. The rapid decrease in the viability of sperm in water is probably important for maintaining the genetic integrity of the spawners; its significance for practical laboratory work is that sperm should be added to the eggs and not vice versa.

Sperm tended to be more active and to remain motile longer in water from the Salton Sea than in ordinary seawater from La Jolla, Calif. Moreover, developing eggs always floated in Salton Sea water (salinity in 1970, about 37 ‰ on the basis of total dissolved solids), while they sank in La Jolla seawater (33.5 ‰). These observations may have important implications for the salinity tolerance and adaptability of Salton Sea fishes (transplanted originally from the Gulf of California), matters of crucial interest in the initiation of this study of fish reproductive physiology.

Several batches of eggs obtained from hormone-induced spawning were allowed to develop to hatching, and a few of the resulting larvae were reared to metamorphosis in the laboratory on a diet of rotifers, *Branchionus plicatilis*, followed by brine shrimp, *Artemia salina*, nauplii. Thus the entire life history of the gulf croaker can probably be completed under controlled laboratory conditions. This opens up the possibility of using this species for many other biological studies where large numbers (50,000-100,000) of pelagic eggs are desired from a marine species of known genetic history. Some of these studies are now in progress (Robert C. May, Scripps Institution of Oceanography, personal communication). It is hoped that future studies will include comparative work on this species, especially with respect to the possible adaptations of Salton Sea croakers since their separation from the Gulf of California population.

SUMMARY

1. Adult and immature gulf croakers captured by beach seining in the Salton Sea were transported to the Fishery-Oceanography Center laboratory in La Jolla, Calif., and used in laboratory studies on gonad maturation and hormone-induced spawning.

2. A bacterial disease which invariably developed on recently captured or frequently handled fish was successfully treated with Furacin antibiotic.

3. Long photoperiods (16 hr of light per 24 hr) and warm water (22° C), along with optimal feeding, accelerated the gonadal maturation of females captured prior to their natural cycle of gonadal maturation. These fish were ready to spawn in the laboratory 1 to 3 months prior to the spawning season observed in the Salton Sea. Male fish became ripe under all combinations of laboratory conditions and remained ripe throughout the study.

4. Concomitant field studies confirmed earlier work showing that female croakers ripened in April, while day length was increasing, and spawned when the water temperature reached about 20° C; peak spawning occurred in May of 1969 and 1970.

5. Mature fish, captured during the spawning season at the Salton Sea, quickly resorbed their gonads when held under short photoperiods (10 hr of light) in the laboratory, but similar fish

maintained on long photoperiods (16 hr of light) remained in spawning condition for 2 months (at 22° C) or 3 months (at 14° C) beyond the normal season.

6. At 14° C, injection of mature fish with salmon pituitary, carp pituitary, chorionic gonadotropin from human pregnancy urine (HCG), and deoxycorticosterone acetate (DOCA) caused increases in gonad size over sham-injected or uninjected fish.

7. A single injection of 1 mg (acetone dried) salmon pituitary, 50 IU of gonadotropin from pregnant mare serum (PMS) or 50 IU of HCG induced spawning in mature croakers (50-100 g) with gonad index values about 5 %. Fish with gonad index values below about 5 % did not respond to otherwise adequate hormone doses. Hormone-spawned fish could be spawned a second or third time at 1- to 2-month intervals.

8. Eggs could be stripped from the fish an average of 30.4 hr following injection. This latent period consisted of a slow hydration phase of water uptake followed by a rapid ovulation phase which released eggs from the follicles into the ovarian lumen.

9. The eggs remained viable only for 1 to 2 hr following ovulation, unless they were stripped from the fish and stored in moist chambers. Each female produced 700 to 1000 eggs per gram of wet body weight.

10. Sperm are viable for less than 30 sec after dispersion in water.

11. Low dosages (0.1 mg) of salmon pituitary were insufficient to cause hydration, while very high dosages (5 mg) caused hydration but, evidently, inhibited ovulation. High dosages (100 IU) of HCG caused fish to overhydrate and eventually die without having ovulated.

12. Carp pituitary caused hydration but was inadequate for ovulation. Deoxycorticosterone acetate and oxytocin, given alone, had little or no effect on the fish.

13. Fish did not respond to single hormone injections if the water temperature was at or below 17° C. One day of acclimation to a higher temperature was sufficient to prepare fish from cold water for spawning.

14. A few larvae hatched from eggs obtained by hormone-induced spawning were reared through metamorphosis; thus, the entire life cycle of the gulf croaker can be completed under laboratory conditions.

ACKNOWLEDGMENTS

Many people contributed to the total success of this project, a cooperative effort made possible by Alex Calhoun, Chief of Inland Fisheries, California Department of Fish and Game, and Reuben Lasker, Program Director for Behavior and Physiology, National Marine Fisheries Service Fishery-Oceanography Center, La Jolla. Their interest made possible the funds and facilities for this study, supported by Federal Aid to Fish Restoration Funds, Dingell-Johnson Project California F-24-R, "Salton Sea Investigations."

Robert F. Elwell, Senior Research Supervisor, IFB, Sacramento, saved me from many administrative details and provided aid and encouragement at critical points in time. Fred Murin, Salton City, was my able field assistant and companion; and David Crear, now at the University of Hawaii, was of inestimable value in our laboratory ventures. Robert C. May, Scripps Institution of Oceanography, La Jolla, contributed much of his time to the successful completion of the study.

Technical assistance was provided by Charles F. Wright and Bert D. Kitchens, National Marine Fisheries Service Fishery-Oceanography Center, La Jolla, who built the fish-holding facilities and maintained the critical seawater supply. W. H. Jochimsen and D. R. Von Allmen, Nimbus Fish Hatchery, Rancho Cordova, arranged for me to collect salmon pituitaries. David Powell, Curator of Fishes, Sea World-San Diego, taught me how to transport and care for fish, and Vince Catania, California Department of Fish and Game at Antioch, showed me how to capture Salton Sea fishes. To each of these persons I extend my gratitude for their help, interest, and ideas.

I also thank the many other members of the California Fish and Game Department and interested Salton Sea sportsmen and merchants

that provided aid, comfort, and fellowship which made the sometimes arduous field work a pleasant and rewarding experience.

LITERATURE CITED

AHSAN, S. NAZAR, AND WILLIAM S. HOAR.
1963. Some effects of gonadotropic hormones on the threespine stickleback, *Gasterosteus aculeatus*. Can. J. Zool. 41(6): 1045-1053.

ATZ, JAMES W., AND GRACE E. PICKFORD.
1959. The use of pituitary hormones in fish culture. Endeavour 18(71): 125-129.
1964. The pituitary gland and its relation to the reproduction of fishes in nature and in captivity. An annotated bibliography for the years 1956-1963. FAO (Food Agr. Organ. U.N.) Fish. Biol. Tech. Pap. 37, 61 p.

BALL, J. N.
1960. Reproduction in female bony fishes. Symp. Zool. Soc. London 1: 105-135.

BALL, ROBERT C., AND EDWARD H. BACON.
1954. Use of pituitary material in the propagation of minnows. Progr. Fish-Cult. 16(3): 108-113.

BARDACH, JOHN E.
1968. The status and potential of aquaculture. Vol. 2, particularly fish culture. American Institute of Biological Sciences, Washington, D.C. Available Clearinghouse for Federal Scientific and Technical Information, Springfield, Va., as PB 177 768, 225 p.

BREDER, CHARLES M., JR., AND DONN ERIC ROSEN.
1966. Modes of reproduction in fishes. Natural History Press, Garden City, N.Y. xv + 941 p.

CARPELAN, LARS H.
1961. Physical and chemical characteristics. *In* Boyd W. Walker (editor), The ecology of the Salton Sea, California, in relation to the sportfishery, p. 17-32. Calif. Dep. Fish Game, Fish Bull. 113.

CHAUDHURI, HIRALAL.
1960. Experiments on induced spawning of Indian carps with pituitary injections. Indian J. Fish. 7(1): 20-48.

CLEMENS, HOWARD P., AND F. BLAKE GRANT.
1964. Gonadal hydration of carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*) after injections of pituitary extracts. Zoologica (New York) 49(4): 193-210.

CLEMENS, HOWARD P., AND KERMIT E. SNEED.
1962. Bioassay and use of pituitary materials to spawn warm-water fishes. U.S. Fish Wildl. Serv., Res. Rep. 61, iv + 30 p.

DAS, S. M., AND H. A. KHAN.
1962. The pituitary and pisciculture in India, with an account of the pituitary of some Indian fishes and a review of techniques and literature on the subject. Ichthyologica 1(1-2): 43-58.

DODD, J. M.
1955. The hormones of sex and reproduction and their effects in fish and lower chordates. Mem. Soc. Endocrinol. 4: 166-187.

FINUCANE, JOHN H.
1970. Pompano mariculture in Florida. Amer. Fish Farmer 1(4): 5-10.

FONTENELE, OSMAR.
1955. Injecting pituitary (hypophyseal) hormones into fish to induce spawning. Progr. Fish-Cult. 17(2): 71-75.

FROGNER, KARL J., AND JOHN R. HENDRIKSON.
1970. A technique for coelomic administration of drugs to fish without handling. Progr. Fish-Cult. 32(3): 142-146.

GUNTER, GORDON.
1967. Vertebrates in hypersaline waters. Contrib. Mar. Sci. 12: 230-241.

HARADA, T.
1970. The present status of marine fish cultivation research in Japan. Helgolaender wiss. Meeresunters. 20: 594-601.

HARRINGTON, ROBERT WHITING, JR.
1959. Photoperiodism in fishes in relation to the annual sexual cycle. *In* Robert B. Withrow (editor), Photoperiodism and related phenomena in plants and animals, p. 651-667. AAAS (Amer. Ass. Advan. Sci.) Publ. 55.

HEDGPETH, J. W.
1959. Some preliminary considerations of the biology of inland mineral waters. Arch. Oceanogr. Limnol. 11 (Suppl.): 111-139.

HENDERSON, NANCY E.
1963. Influence of light and temperature on the reproductive cycle of eastern brook trout, *Salvelinus fontinalis* (Mitchill). J. Fish. Res. Bd. Can. 20(4): 859-897.

HICKLING, C. F.
1962. Fish culture. Faber and Faber, London. 259 p.

HOAR, WILLIAM S.
1969. Reproduction. *In* W. S. Hoar and D. J. Randall (editors), Fish physiology. Vol. 3, p. 1-72. Academic Press, New York.

HOAR, W. S., AND D. J. RANDALL (editors).
1969, 1970. Fish physiology. Academic Press, New York. 5 vol.

HORA, S. L., AND T. V. R. PILLAY.
1962. Handbook on fish culture in the Indo-Pacific region. FAO (Food Agr. Organ. U.N.) Fish. Biol. Tech. Pap. 14, vii + 204 p.

HYDER, MOHAMED.
1970. Histological studies on the testes of pond specimens of *Tilapia nigra* (Gunther) (Pisces: Cichlidae) and their implications of the pituitary-testis relationship. Gen. Comp. Endocrinol. 14(1): 198-211.

JOSEPH, EDWIN B., AND VISHNU P. SAKSENA.
1966. Determination of salinity tolerances in mummichog (*Fundulus heteroclitus*) larvae obtained from hormone-induced spawning. Chesapeake Sci. 7(4): 193-197.

KUNTZ, ALBERT.
1914. The embryology and larval development of *Bairdiella chrysura* and *Anchovia mitchilli*. U.S. Bur. Fish., Bull. 33: 3-19.

LASKER, REUBEN, AND LILLIAN L. VLYMEN.
1969. Experimental sea-water aquarium. U.S. Fish Wildl. Serv., Circ. 334, iv + 14 p.

LEITRITZ, EARL.
1959. Trout and salmon culture (hatchery methods). Calif. Dep. Fish Game, Fish Bull. 107, 169 p.

LILEY, N. R.
1969. Hormones and reproductive behavior in fishes. *In* W. S. Hoar and D. J. Randall (editors), Fish physiology. Vol. 3, p. 73-116. Academic Press, New York.

MALVEN, P. V.
1970. Interaction between endocrine and nervous systems. Bioscience 20(10): 595-601.

MCINERNEY, JOHN E., AND DAVID O. EVANS.
1970. Action spectrum of the photoperiod mechanism controlling sexual maturation in the threespine stickleback, *Gasterosteus aculeatus*. J. Fish Res. Bd. Can. 27(4): 749-763.

NEW, D. A. T.
1966. The culture of vertebrate embryos. Logos Press, Academic Press, London. x + 245 p.

PERKS, A. M.
1969. The neurohypophysis. *In* W. S. Hoar and D. J. Randall (editors), Fish physiology. Vol. 2, p. 111-205. Academic Press, New York.

PICKFORD, GRACE E., AND JAMES W. ATZ.
1957. The physiology of the pituitary gland of fishes. New York Zoological Society, New York. xxiii + 613 p.

SHELBOURNE, J. E.
1964. The artificial propagation of marine fish. *In* F. S. Russell (editor), Advances in marine biology. Vol. 2, p. 1-83. Academic Press, London.
1970. Marine fish cultivation: Priorities and progress in Britain. *In* William J. McNeil (editor), Marine aquiculture, p. 15-36. Oregon State University Press, Corvallis.

SNEED, KERMIT E., AND HOWARD P. CLEMENS.
1959. The use of human chorionic gonadotrophin to spawn warm-water fishes. Progr. Fish-Cult. 21(3): 117-120.

STEVENS, ROBERT E.
1966. Hormone-induced spawning of striped bass for reservoir stocking. Progr. Fish-Cult. 28(1): 19-28.

SUNDARARAJ, BANGALORE I., AND SHASHI V. GOSWAMI.
1966. Effects of mammalian hypophysial hormones, placental gonadotrophins, gonadal hormones, and adrenal corticosteroids on ovulation and spawning in hypophysectomized catfish, *Heteropneustes fossilis* (Bloch). J. Exp. Zool. 161(2): 287-295.
1968. Some aspects of induced spawning in the hypophysectomized catfish, *Heteropneustes fossilis*. *In* Symposium on comparative endocrinology, p. 189-193. Nat. Inst. Sci. India, New Delhi.

TSUYUKI, H., P. J. SCHMIDT, AND M. SMITH.
1964. A convenient technique for obtaining pituitary glands from fish. J. Fish. Res. Bd. Can. 21(3): 635-637.

WALKER, BOYD W.
1952. A guide to the grunion. Calif. Fish Game 38(3): 409-420.

WALKER, BOYD W. (editor).
1961. The ecology of the Salton Sea, California, in relation to the sportfishery. Calif. Dep. Fish Game, Fish Bull. 113, 204 p.

WHITNEY, RICHARD R.
1961. The bairdiella, *Bairdiella icistius* (Jordan and Gilbert). *In* Boyd W. Walker (editor), The ecology of the Salton Sea, California, in relation to the sportfishery, p. 105-151. Calif. Dep. Fish Game, Fish Bull. 113.
1967. Introduction of commercially important species into inland mineral waters, a review. Contrib. Mar. Sci. 12: 262-280.

WICKLER, W.
1966. Breeding aquarium fish; an introduction to the biology of their reproduction [in German]. Transl. by D. W. Tucker. Van Nostrand, Princeton, N.J. 112 p.

WIEBE, JOHN P.
1968. The effects of temperature and daylength on the reproductive physiology of the viviparous seaperch, *Cymatogaster aggregata* Gibbons. Can. J. Zool. 46(6): 1207-1219.

YAMAZAKI, FUMIO, AND EDWARD M. DONALDSON.
1968a. The spermiation of goldfish (*Carassius auratus*) as a bioassay for salmon (*Oncorhynchus tshawytscha*) gonadotropin. Gen. Comp. Endocrinol. 10(3): 383-391.
1968b. The effects of partially purified salmon pituitary gonadotropin on spermatogenesis, vitellogenesis, and ovulation in hypophysectomized goldfish (*Carassius auratus*). Gen. Comp. Endocrinol. 11(2): 292-299.

HARMONIC FUNCTIONS FOR SEA-SURFACE TEMPERATURES AND SALINITIES, KOKO HEAD, OAHU, 1956-69, AND SEA-SURFACE TEMPERATURES, CHRISTMAS ISLAND, 1954-69

GUNTHER R. SECKEL[1] AND MARIAN Y. Y. YONG[2]

ABSTRACT

Harmonic functions have been fitted to time-series, sea-surface temperatures and salinities in order to facilitate studies of the oceanographic climate near Hawaii and Christmas Island. The manner in which Fourier analysis has been adapted to this application has been described. The standard errors of estimate for Koko Head temperatures and salinities are less than 0.26° C and less than 0.05‰, respectively. The standard errors of estimate for Christmas Island temperatures are approximately 60 % above those for the Koko Head temperature. The expected values of the Koko Head temperature and salinity functions have an uncertainty of ±0.1° C and ±0.015‰, respectively, when samples are obtained twice weekly. Error terms of the Christmas Island temperatures, with daily sampling, are on average 0.07° C. Harmonic analysis spanning the entire sampling duration shows that long-term variations in the Christmas Island temperature and Koko Head salinity are larger than the seasonal variations. Seasonal variations in the Koko Head temperatures are dominant and longer term variations small. The results of the harmonic analyses are presented in the appendixes: (1) a listing of coefficients that define the Koko Head temperature and salinity functions for each year and the Christmas Island temperature functions for each quarter of each year, (2) graphs of the fitted curves together with the observed values for each year.

In this paper harmonic functions are presented of sea-surface temperatures and salinities that have been regularly measured near Koko Head, Oahu (lat. 21°16′ N., long. 157°41′ W.) since 1956 and at Christmas Island (lat. 1°51′ N., long. 157°23′ W.) since 1954 (Fig. 1).

Sea-surface temperatures and salinities change in response to, and therefore reflect, sea-air interaction processes (heat exchange, evaporation minus precipitation) and oceanographic processes (advection, diffusion). For example, the mean sea-surface temperature for a month at Koko Head provides a measure of the mean heat content of the water near the surface. Thus, if the mean temperature for March is above that for February, then meteorological and oceanographic processes must have taken place to raise the mean heat content of

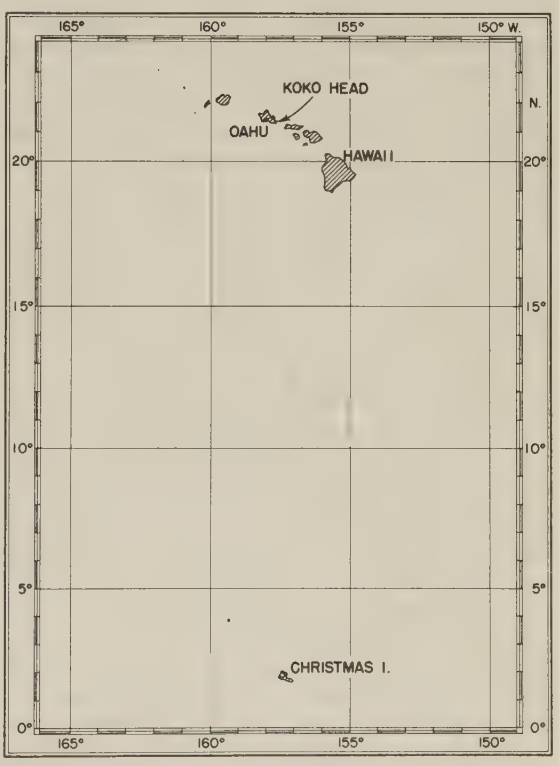


FIGURE 1.—Location of Koko Head, Oahu and Christmas Island.

[1] National Marine Fisheries Service Environmental and Fishery Forecasting Center, Monterey, Calif. 93940; formerly National Marine Fisheries Service Hawaii Area Fishery Research Center, Honolulu, Hawaii.

[2] National Marine Fisheries Service Hawaii Area Fishery Research Center, Honolulu, Hawaii 96812.

Manuscript received September 1970.
FISHERY BULLETIN: VOL. 69, NO. 1, 1970.

the surface water in March above that in February. This concept was used in studies of the Hawaiian oceanographic climate (Seckel, 1962, 1969) and has been applied to Hawaiian fishery problems (Seckel and Waldron, 1960; Seckel, 1963).

Rigorously, the theory of distribution of properties in the sea states that the change of sea-surface temperature during a time interval, say from the first day of one month to the first day of the next month, is equal to the integral of all meteorological and oceanographic processes affecting the temperature during the time interval:

$$\theta_b - \theta_a = \int_a^b (\text{all processes})\, dt.$$

θ_a is the temperature at the beginning and θ_b is the temperature at the end of the interval. In application, the choice of θ_a and θ_b presents the following problems: The difference in the observed temperatures at times a and b also reflects the effect of short-term variability ("noise") that is not of interest in monitoring the large-scale events. If one uses monthly mean temperatures in the heat budget equation that include observations made 15 days before and after times a and b, then the change of temperature incorporates the effect of processes that lie outside the interval of interest. Although mean values usually provide an adequate measure of the temperature change during given time intervals, the true change of temperature can be obscured. One can overcome the problems caused by the two unsatisfactory methods of obtaining measures of the temperature change by finding suitable functions that filter out undesirable short-term variability without obscuring the basic temperature and salinity trends.

Techniques that can be used in the smoothing of time series data have been reviewed by Holloway (1958) and usually involve moving averages of the data to which weighting factors have been assigned.

Curve fitting provides another method of approach. A useful technique that has been used in this report, is to obtain an analytic expression for the temperature and salinity as a function of time by Fourier analysis. The Fourier series is efficiently, and therefore inexpensively, derived by computer. Efficiency is furthered in that graphs can be produced by automatic plotter. The Fourier series provides a least-squares fit of the observed values. It permits filtering of undesired variability, facilitates statistical evaluation of the data, and—within limits—provides insight into the properties of the distribution.

These advantages will become apparent in the following sections of this report. The results of the analyses for each year of observation are presented in the appendix in both tabular and graphical form.

THE FOURIER METHOD

Fourier series are well known, widely applied, and adequately described in texts of advanced calculus. A good description can be found in Sokolnikoff (1939) where the derivation of the Fourier coefficients by least-squares method is also presented.

The temperature or salinity is expressed as a function of time, t, in the Fourier series:

$$S_n(t) = \frac{A_0}{2} + \sum_n (A_n \cos n\omega t + B_n \sin n\omega t), \quad n = 1,2,3,\ldots k$$

where $\omega = \frac{2\pi}{T}$, and T is the fundamental period. For example, if harmonic analysis is to be performed on data collected for a duration of 1 year, T would be 365 days.

The Fourier series contains the coefficients A_0, A_n, and B_n that are given by the Fourier integrals

$$A_n = \frac{2}{T} \int_0^{t=T} F(t)\cos(n\omega t)dt, \quad n = 0,1,2, \ldots k,$$

and

$$B_n = \frac{2}{T} \int_0^{t=T} F(t)\sin(n\omega t)dt, \quad n = 1,2,3, \ldots k.$$

The coefficient A_0 is the special case of A_n with $n = 0$. In our application $F(t)$ is the temperature or salinity at the time t. Of course, the functional relationship between temperature and time or salinity and time is not known so that

$F(t)$ is the observed temperature or salinity at the time t. Furthermore, $F(t)$ is known only at finite intervals of time so that the above Fourier integrals must be obtained by numerical integration. This integration, approximating the area under the curves $F(t)$ cos $(n\omega t)$ and $F(t)$ sin $(n\omega t)$, is performed by summing areas of rectangles with height $G(t)$ cos $(n\omega t)$ or $G(t)$ sin $(n\omega t)$, and with width Δt, the sampling interval.

The finite difference form of the Fourier integrals is

$$A_n = \frac{2}{T} \sum_{i=1}^{m} G(t)_i \cos(n\omega t)\Delta t_i, \quad n = 0,1,2, \ldots k,$$

and

$$B_n = \frac{2}{T} \sum_{i=1}^{m} G(t)_i \sin(n\omega t)\Delta t_i, \quad n = 1,2,3, \ldots k.$$

The number of samples in the interval $t = 0$ to $t = T$ is $m + 1$,

$$\Delta t_i = t_i - t_{i-1},$$

and $$G(t)_i = \tfrac{1}{2}[F(t_i) + F(t_{i-1})], \quad i = 1,2,3, \ldots m.$$

The time used to evaluate the geometric factor is $\frac{1}{2}$ $(t_i + t_{i-1})$. Other schemes of obtaining the best estimate of $G(t)$ cos $(n\omega t)$ during the interval Δt can be used but would not significantly affect the results in our application (see Kaplan, 1953: p. 168-172).

Library programs for the evaluation of Fourier coefficients by computer usually require that the sampling interval, Δt, be constant. Since this condition is not necessarily met in our application, a more flexible computer program was written to evaluate the coefficients. In this program the sampling interval may vary, and the number of samples for the basic period of analysis need not be the same in each application.

The Fourier coefficients evaluated in the above manner enable us to describe analytically the temperature or salinity as a function of time. If we wish to go further and gain insight into the properties of the temperature or salinity distribution, it is more useful to express the Fourier series as a sum of cosines:

$$S_n(t) = \frac{A_0}{2} + \sum_n C_n \cos\, \omega(nt - \alpha_n), \qquad n = 1,2,3, \ldots k.$$

The transformation is accomplished by the use of the trigonometric indentities

$$A_n = C_n \cos\, \omega\alpha_n,$$

$$B_n = C_n \sin \omega\alpha_n,$$

$$C_n = \pm(A_n^2 + B_n^2)^{1/2},$$

and $$\omega\alpha_n = \arctan \frac{B_n}{A_n}.$$

In the application described in this report the fundamental period in the Fourier series is the sampling duration or any portion of this duration that may be arbitrarily chosen; the amplitudes and phase angles do not necessarily coincide with natural variations in temperature or salinity; and the harmonic functions have no predictive value.

In some cases, such as the Koko Head temperatures with a well-defined annual cycle, the fundamental period of the Fourier series derived for each year approximates the annual cycle. At Christmas Island, however, an annual temperature cycle is not always clearly apparent. Despite the fact that choice of the fundamental period may be arbitrary and may not coincide with a naturally occurring period, the spectrum is resolved beyond the first few harmonics. For example, if the fundamental period, $n = 1$, is 12 months then the period of the first harmonic, $n = 2$, is 6 months. A naturally occurring 9 months cycle in the observations would in this case not be resolved. As n increases, however, resolution improves to 4, 3, 2.4, 2, etc., months.

The highest harmonic, or n-value, to which harmonic analysis can be carried, is limited by the number of observations. In the ideal case and when samples are equally spaced in time, there must be at least $2n$ observations, i.e., at least two samples per cycle. In nature, where we are dealing with noncyclical variations and unequal spacing of samples a sinusoidal curve cannot be resolved with only two samples, and

a minimum of four or, better, six samples is required to achieve good resolution. For example, sea-surface temperatures are to be monitored and the fundamental period of observations is to be 12 months. Resolution of a 1-month cycle ($n = 12$), requires four samples per month, or sampling once per week.

APPLICATION OF THE FOURIER METHOD

In practice, the Fourier method described above must be adapted to each specific application. In addition to the minimum number of samples necessary in order to attain a desired resolution another restriction applies to variations in the sampling interval. Although the computer program used to obtain the results of this paper allows a varying sampling interval, thus accepting a sequence with missing observations, the sampling interval can be allowed to vary only within limits. For example, at least four samples per month are necessary to resolve a monthly cycle. This cycle will, however, not be resolved if the samples are taken on four consecutive days, rather than being evenly distributed throughout the month. It is also possible to aid the harmonic analysis in rapid convergence to its best fit with the observed values by adjusting the fundamental period of analysis and by performing some preliminary operations which are described below.

APPLICATION TO KOKO HEAD SEA-SURFACE TEMPERATURES AND SALINITIES

The sampling station is located near Koko Head at the exposed, eastern shore of Oahu so that the sea-surface temperatures and salinities measured there reflect open-ocean conditions. The salinities appear to be affected by runoff only on rare occasions of heavy rainfall. Both the temperatures and salinities are based on bucket samples. The salinity is determined in the Hawaii Area Fishery Research Center, Honolulu.

Before 1961 samples were collected at weekly intervals and subsequently twice weekly, usually on Tuesday and Friday mornings. Occasionally sampling has been missed. The computer program must therefore accept data with an irregular sampling interval.

The basic period for analysis has been chosen to be 1 year. Harmonic analysis began with the first sample and ended with the last sample of the year. The sampling time, in days and months, was converted to days of the year beginning with the first of the year.

Owing to a longer term trend, the value of a property at the beginning is not necessarily the same as at the end of an annual cycle. In the case of Koko Head salinities and Christmas Island temperatures, it will be seen later that an annual cycle is, in fact, not always apparent. The noncyclic trend during the analysis period can be obtained by linear approximation. Rapid convergence to the best fitting function can then be achieved by performing the harmonic analysis on the residuals of the observed values from a linear fit.

In our application the first observed value, $F(t_0)$, and the last observed value, $F(t_l)$, for the period were used to obtain the linear equation

$$S' = F(t_0) + bt$$

where $$b = \frac{F(t_l) - F(t_0)}{t_l - t_0}.$$

The residuals, $R_m = F(t_m) - [F(t_0) + bt_m]$, $m = 0.1,2,\ldots l$, were used to obtain the Fourier coefficients. The Koko Head temperatures and salinities for each year are then expressed by the function

$$S = K + bt + \sum_{n=1}^{k} C_n \cos\omega(nt - \alpha_n)$$

where $$K = F(t_0) + \frac{A_0}{2} \text{ and } \omega = \frac{2\pi}{T}.$$

The phase angles and coefficients for each of the years 1956-69 of the sea-surface temperatures are listed in appendix A Table 1, and of the sea-surface salinity are listed in appendix A Table 2.

The functions for each year together with the observed values of the sea-surface temperature and salinity have been drawn by automatic plotter and are presented in appendix B.

Quality control of the data was achieved by two passes of the data through the computer. First, the fitted graphs and plots of the observed values as well as listed deviations of observed values from the functions that resulted from the first computer analysis were used to reject obviously erroneous observations. The analysis was then repeated without the rejected observations. The tabulations in appendix A and figures in appendix B are the result of the second pass through the computer. The rejected values are plotted and identified in the figures of appendix B.

APPLICATION TO CHRISTMAS ISLAND SEA-SURFACE TEMPERATURES

The Christmas Island sea-surface temperatures are measured with a bucket thermometer each morning (about 0900 local time) in the channel leading from the open sea to the lagoon. The differences between open sea and lagoon water temperatures have not been determined. It is reasonable to assume that these temperatures differ, and so introduce variability in the observed temperature as tidal currents in the channel change from day to day. The tide-induced variability will, however, not be reflected by a harmonic function where the resolution of the highest harmonic is longer than 1 month. Although the sampling site is not ideal, the observed temperatures are believed to reflect, with some bias induced by lagoon temperatures, the changes of sea-water temperature from month to month.

The procedure to obtain functions of the Christmas Island temperatures was the same as that used for the Koko Head temperatures and salinities with the exception that a different fundamental period was chosen. In contrast to Koko Head where an annual cycle dominates the sea-surface temperature, longer term changes dominate the temperature at Christmas Island. The basic temperature pattern at Christmas Island also changes from year to year. For these reasons a duration of 120 days was chosen as fundamental period and Fourier analysis was performed, as before, on the residuals of the observed values from a linear fit.

For each year, the 120-day periods followed in sequence with an overlap of 30 days. The periods ran from the first day of the year to day 120, from day 91 to day 210, from day 181 to day 300, and from day 271 to day 390, extending 25 days into the following year. In this manner rapid convergence of the harmonic function to the best fit was obtained.

With daily sampling and a fundamental period of 120 days, harmonic analysis could be carried to the harmonic $n = 30$, but to do so would introduce variability that we wish to smooth out. Although a resolution of 1 month requires harmonic analysis to $n = 4$ only, the analysis was arbitrarily carried out to $n = 7$, resolving a period of 16 days.

The resulting phase angles and coefficients for 1954-69 of the sea-surface temperature are listed in appendix C. The functions for each year together with the observed values have been drawn by automatic plotter and are presented in appendix D.

Quality control procedures were identical to those for the Koko Head analyses. Relatively large data gaps occurred at Christmas Island in 1964, 1967, and 1968. Because some observations were available during each of the 120-day periods in question, harmonic analysis produced coefficients that enabled drawing of curves in appendix D although there were no data. These curves were not erased since it is instructive to see what harmonic analysis will do when faced with insufficient data.

DISCUSSION OF RESULTS

In this paper we are concerned with the derivation and presentation of harmonic functions of regularly observed sea-surface temperatures and salinities at fixed stations rather than with oceanographic interpretations. In the discussion of the results we will, therefore, concern ourselves primarily with the quality of fit of the functions. We will also briefly discuss some properties of the temperature and salinity distributions that are reflected by the functions and, finally, show functions spanning the entire time of observations.

QUALITY OF FIT

A superficial inspection of the figures in appendixes B and D shows that the harmonic functions follow the trend of the observed values very well. Closer inspection, however, reveals that there are cases where the fitted curves depart from the observed trend. An example occurred when the Koko Head salinity function (appendix B) for 1956 fluctuated about the observed values from day 145 to day 180. The fluctuations were caused by a data gap between these days. A 15-day data gap is too large when harmonic analysis resolves a period of 1 month. Another example of deviations occurred in the Christmas Island temperature function (appendix D) for 1968 between day 240 and day 275. Again, a 30-day data gap is too large when harmonic analysis resolves a period of 19 days.

These examples illustrate that the sampling interval in harmonic analysis may vary only within limits and that the interval of permissible sampling gaps depends upon the period resolved by the analysis. In cases such as were cited, where the fundamental period of analysis is much longer than the sampling gap, it is possible to constrain the harmonic function by inserting "dummy" values based on linear interpolation of the last sample before, and the first sample after, the data gap.

There are cases where the fitted curve fails to follow the observed trend. When the deviations from the fitted curves are relatively large, there is a tendency to reject the observed values during quality control procedures, blaming the deviations on erroneous sampling. Temperature deviations of this type occurred at Koko Head during days 65 to 90 of 1967. First the observed temperatures fell to 0.6° C below the fitted curve and then rose abruptly 1.3° to 0.6° C above the fitted curve. Erroneous sampling is ruled out since more than one sample was involved in establishing the trend that was abruptly broken and, in addition, the salinity showed similar variability during the same time interval. First the observed salinity rose to 0.15‰ above the expected value and then dropped abruptly 0.37‰ to 0.16‰ below the expected value. In the Hawaiian region the temperature increases and the salinity decreases southward. Thus, northward-southward displacements of the water that would result in the observed temperature and salinity changes were the probable cause for the large deviations rather than sampling error.

In order to assess the quality of fit quantitatively, we will consider several aspects of the standard error of estimate (root mean square deviations of the observed from the expected values). This statistical parameter is listed in three tables for each function, with harmonic analysis carried out for the fundamental period, the first harmonic, the second harmonic, etc. ($n = 1,2,3,\ldots$). Table 1 applies to Koko Head temperatures, Table 2 to Koko Head salinities, and Table 3 to Christmas Island temperatures.

In each case the listed standard error of estimate decreases or reaches a constant value with increasing n. The fit of the function therefore improves or levels off as the analysis is carried out to higher harmonics. Exceptions to this trend occurred in 1956, 1959, and 1961 when the standard errors of estimate for the Koko Head salinity functions (Table 2) increase as the highest n values are reached. Prior to May 1961, only four or five samples per month were obtained at Koko Head and therefore the highest n value permitted by the sampling frequency had been reached. In addition, sampling gaps occurred in 1956, as mentioned before, and in 1961 between days 220 and 241.

The fit of the Koko Head temperature functions (Table 1) improves most rapidly during the first few harmonics and with analysis carried out to $n = 6$, the standard error of estimate is near or below 0.3° C. With analysis carried out to $n = 13$, the standard error of estimate is below 0.2° C for all years excepting 1963 and 1965-68.

Greatest improvement of fit for the Koko Head salinity functions (Table 2) does not always occur during the first few harmonics but continues as analysis is carried beyond $n = 6$. In 1960, for example, the standard error of estimate with analysis to $n = 1$, $n = 6$, and $n = 13$, is 0.090‰, 0.075‰, and 0.038‰, respectively. The standard error of estimate at the n value of best fit in Table 2 is below 0.04‰ except

TABLE 1.—Standard error of estimate (° C) for each annual temperature function at Koko Head, 1956-68, with harmonic analysis carried out in sequence to $n = 1, 2, 3, \ldots$ and 13.

	N-VALUES												
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13
1956	0.21	0.19	0.17	0.16	0.16	0.14	0.14	0.14	0.13	0.13	0.12	0.12	0.11
1957	0.36	0.29	0.24	0.24	0.23	0.23	0.23	0.21	0.20	0.20	0.19	0.19	0.18
1958	0.31	0.29	0.24	0.24	0.22	0.22	0.22	0.22	0.22	0.20	0.20	0.18	0.17
1959	0.41	0.38	0.29	0.29	0.26	0.24	0.24	0.24	0.22	0.21	0.20	0.20	0.19
1960	0.30	0.27	0.24	0.24	0.23	0.23	0.22	0.22	0.19	0.19	0.17	0.16	0.15
1961	0.47	0.37	0.35	0.33	0.32	0.31	0.31	0.28	0.24	0.23	0.20	0.18	0.17
1962	0.32	0.25	0.25	0.25	0.23	0.21	0.21	0.21	0.20	0.19	0.19	0.19	0.17
1963	0.30	0.29	0.28	0.28	0.27	0.26	0.23	0.23	0.21	0.21	0.21	0.21	0.21
1964	0.29	0.29	0.28	0.25	0.25	0.24	0.23	0.21	0.20	0.18	0.17	0.17	0.16
1965	0.49	0.45	0.38	0.36	0.34	0.30	0.28	0.27	0.27	0.27	0.27	0.26	0.26
1966	0.43	0.32	0.32	0.30	0.30	0.27	0.27	0.27	0.26	0.26	0.26	0.26	0.26
1967	0.44	0.40	0.34	0.33	0.32	0.27	0.26	0.25	0.25	0.24	0.24	0.24	0.23
1968	0.37	0.32	0.28	0.28	0.28	0.27	0.26	0.25	0.24	0.24	0.23	0.23	0.23

TABLE 2.—Standard error of estimate (‰) for each annual salinity function at Koko Head, 1956-68, with harmonic analysis carried out in sequence to $n = 1, 2, 3, \ldots$ and 13.

	N-VALUES												
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13
1956	0.045	0.034	0.032	0.031	0.031	0.030	0.030	0.029	0.028	0.025	0.025	0.028	0.030
1957	0.068	0.057	0.054	0.054	0.045	0.041	0.039	0.037	0.034	0.034	0.032	0.030	0.030
1958	0.069	0.066	0.059	0.059	0.056	0.053	0.053	0.052	0.049	0.048	0.041	0.036	0.036
1959	0.174	0.099	0.076	0.075	0.074	0.073	0.069	0.064	0.060	0.058	0.054	0.053	0.054
1960	0.090	0.083	0.081	0.078	0.077	0.075	0.069	0.063	0.056	0.053	0.050	0.042	0.038
1961	0.064	0.061	0.051	0.047	0.043	0.038	0.037	0.036	0.033	0.030	0.027	0.028	0.028
1962	0.049	0.046	0.046	0.044	0.043	0.041	0.037	0.037	0.036	0.035	0.034	0.034	0.034
1963	0.054	0.053	0.052	0.046	0.045	0.045	0.043	0.041	0.037	0.037	0.034	0.033	0.033
1964	0.086	0.078	0.069	0.063	0.061	0.059	0.052	0.052	0.051	0.044	0.044	0.043	0.038
1965	0.094	0.085	0.078	0.072	0.072	0.071	0.066	0.064	0.058	0.056	0.054	0.048	0.045
1966	0.044	0.043	0.042	0.037	0.037	0.034	0.034	0.033	0.033	0.030	0.030	0.029	0.028
1967	0.079	0.078	0.074	0.072	0.068	0.061	0.055	0.054	0.052	0.051	0.050	0.046	0.044
1968	0.060	0.057	0.051	0.046	0.042	0.040	0.038	0.038	0.035	0.035	0.033	0.033	0.033

TABLE 3.—Standard error of estimate (° C) for each quarterly temperature function at Christmas Island, 1954-68, with harmonic analysis carried out in sequence to $n = 1, 2, 3, \ldots$ and 7.

		N-VALUES						
YEAR	QUARTER	1	2	3	4	5	6	7
1954	1	0.44	0.41	0.41	0.41	0.32	0.30	0.29
	2	0.36	0.35	0.33	0.33	0.32	0.30	0.30
	3	0.51	0.50	0.50	0.50	0.47	0.45	0.44
	4	0.39	0.38	0.37	0.33	0.30	0.30	0.29
1955	1	0.30	0.28	0.27	0.26	0.26	0.26	0.25
	2	0.29	0.29	0.28	0.28	0.28	0.27	0.26
	3	0.34	0.33	0.33	0.33	0.32	0.32	0.32
	4	0.46	0.45	0.43	0.42	0.40	0.39	0.39
1956	1	0.40	0.38	0.38	0.37	0.36	0.35	0.35
	2	0.52	0.50	0.48	0.48	0.46	0.45	0.45
	3	0.48	0.47	0.45	0.44	0.43	0.41	0.41
	4	0.38	0.38	0.36	0.36	0.36	0.32	0.32
1957	1	0.48	0.46	0.45	0.44	0.43	0.43	0.43
	2	0.61	0.54	0.54	0.54	0.53	0.51	0.51
	3	0.44	0.44	0.43	0.43	0.40	0.39	0.38
	4	0.40	0.39	0.35	0.34	0.33	0.30	0.28
1958	1	0.26	0.25	0.24	0.24	0.24	0.23	0.23
	2	0.33	0.33	0.33	0.32	0.31	0.30	0.29
	3	0.37	0.35	0.30	0.29	0.28	0.28	0.28
	4	0.32	0.31	0.28	0.27	0.26	0.25	0.25
1959	1	0.41	0.34	0.30	0.28	0.28	0.27	0.27
	2	0.40	0.38	0.36	0.35	0.34	0.34	0.33
	3	0.48	0.39	0.36	0.34	0.32	0.32	0.32
	4	0.43	0.39	0.36	0.32	0.31	0.29	0.29
1960	1	0.30	0.29	0.27	0.26	0.26	0.25	0.25
	2	0.35	0.33	0.32	0.31	0.31	0.31	0.31
	3	0.32	0.31	0.30	0.27	0.26	0.26	0.25
	4	0.39	0.32	0.29	0.26	0.26	0.24	0.23
1961	1	0.36	0.34	0.34	0.32	0.31	0.30	0.27
	2	0.34	0.34	0.31	0.27	0.26	0.26	0.25
	3	0.36	0.29	0.29	0.28	0.27	0.25	0.25
	4	0.26	0.24	0.22	0.22	0.20	0.19	0.18
1962	1	0.39	0.34	0.30	0.30	0.30	0.27	0.27
	2	0.38	0.33	0.31	0.30	0.29	0.27	0.25
	3	0.26	0.24	0.21	0.20	0.20	0.19	0.19
	4	0.30	0.26	0.25	0.24	0.24	0.24	0.24
1963	1	0.36	0.36	0.34	0.34	0.32	0.32	0.28
	2	0.46	0.38	0.31	0.30	0.28	0.27	0.21
	3	0.36	0.29	0.29	0.27	0.26	0.25	0.24
	4	0.30	0.29	0.28	0.26	0.26	0.25	0.25
1964	1	0.32	0.32	0.31	0.30	0.29	0.29	0.28
	2	0.37	0.31	0.30	0.29	0.28	0.28	0.27
	3	0.34	0.31	0.29	0.29	0.28	0.27	0.26
	4	0.28	0.27	0.26	0.23	0.22	0.21	0.21
1965	1	0.30	0.29	0.28	0.27	0.26	0.25	0.25
	2	0.36	0.32	0.29	0.29	0.29	0.29	0.29
	3	0.53	0.52	0.45	0.42	0.39	0.38	0.37
	4	0.37	0.32	0.31	0.30	0.30	0.30	0.29
1966	1	0.42	0.39	0.35	0.34	0.33	0.30	0.29
	2	0.42	0.35	0.35	0.34	0.34	0.31	0.30
	3	0.60	0.51	0.48	0.46	0.43	0.42	0.40
	4	0.68	0.68	0.53	0.52	0.51	0.51	0.47
1967	1	0.42	0.40	0.34	0.34	0.34	0.32	0.32
	2	0.40	0.39	0.36	0.36	0.36	0.36	0.35
	3	0.39	0.38	0.37	0.36	0.34	0.33	0.33
	4	0.32	0.30	0.28	0.27	0.27	0.27	0.26
1968	1	0.42	0.37	0.36	0.33	0.33	0.33	0.32
	2	0.37	0.35	0.31	0.31	0.31	0.30	0.30
	3	0.28	0.29	0.29	0.30	0.31	0.28	0.28
	4	0.28	0.27	0.26	0.24	0.23	0.21	0.21

in 1959 and 1965 when it is 0.054‰, and 0.045‰, respectively.

At Christmas Island (Table 3), the average standard error of estimate at $n = 4$ (resolution of 1 month) is near 0.33° C and therefore about 60 % higher than that for the Koko Head temperatures. As previously mentioned, high temperature variability is to be expected at the Christmas Island sampling site.

A standard error of estimate based on all samples used to obtain a function obscures the month-to-month changes in variability that may have occurred. At Koko Head the month-to-month changes in temperature variability as reflected by the standard error of estimate for each month ranges from 0.05° to 0.45° C, the same values for the Koko Head salinities range from 0.006‰ to 0.136‰, and those for Christmas Island temperatures range from 0.17° to 0.66° C. Assuming that sampling error remains constant, the range of variability reflects changes in oceanographic conditions.

The standard error of estimate computed from the temperature and salinity observations of each month also reflects sampling quality in that low values indicate the residual variability in the ocean plus sampling error. For the Koko Head temperature, low values of the monthly standard error of estimate are near 0.1° C and for the Koko Head salinity they are near 0.02‰. The sampling error is therefore within ±0.1° C for the temperature and ±0.02‰ for the salinity. These are the limits to be expected when bucket sampling of the temperature and salinity is carefully done.

Finally, how is the quality of fit affected by sampling frequency and how reliable are the expected values that may be obtained from the harmonic functions? The constraint imposed by the sampling frequency on the resolution that may be attained by harmonic analysis has already been discussed. The present question concerns improvement of fit when the sampling frequency is increased above the minimum requirements.

At Koko Head the sampling frequency was increased from once to twice weekly in 1961. No significant change can be seen in the standard errors of estimate listed in Tables 1 and 2 as a result of doubling the sampling frequency. This observation is consistent with results obtained from oceanographic data collected at Ocean Weather Station "P" in the Gulf of Alaska. Tabata (1964: Table 8) lists the monthly mean value and the standard deviation of the temperature at 10-m depth based on data obtained twice daily, data obtained every second, third, fourth, fifth, sixth, and seventh day of July 1959 and May 1961. For July 1959 the mean temperatures range from 10.70° to 10.81° C and the standard deviations range from 0.60° to 0.76° C. For May 1961 the mean temperatures range from 5.84° to 5.90° C and the standard deviations range from 0.39° to 0.46° C.

In May 1961 Koko Head temperatures and salinities were sampled on 25 days. The mean of all temperature observations was 24.67° C with standard deviation 0.27° C. The mean of temperatures taken every fifth day was 24.58° C with standard deviation 0.39° C. The mean of all salinity observations was 34.759‰ with standard deviation 0.051‰. The mean of salinities taken every fifth day was 34.772‰ with standard deviation 0.058‰. The temperature results from Koko Head are comparable to those from Ocean Weather Station "P" in that mean values and standard deviations based on different sampling frequencies fall within approximately the same range. The standard errors of estimate for the May 1961 Koko Head temperatures and salinities, based on the harmonic functions with resolution of 1 month, are lower than the standard deviations, namely, 0.25° C and 0.027‰, respectively. The standard errors of estimate as well as the standard deviations do not change significantly when the sampling frequency is increased above the required minimum to attain a desired resolution by harmonic analysis.

Increasing the sampling frequency does, however, improve the confidence limits of a mean value or the expected value of a harmonic function. A good measure of the confidence limits of a mean value is the standard error of the mean (the standard deviation divided by the square root of the number of samples). Return-

ing to Tabata's table the standard error of the mean for July 1959 is for twice daily sampling every day 0.086° C, and for twice daily sampling every seventh day 0.253° C. For the same sampling frequencies in May 1961 the standard errors of the mean are 0.053° and 0.15° C, respectively. For the May 1961 Koko Head temperatures the standard error of the mean is 0.055° C with 25 samples and 0.16° C with sampling every fifth day. The standard error of the mean for the May 1961 Koko Head salinities is 0.010‰ with 25 samples and 0.024‰ with sampling every fifth day. On the basis of these considerations, the expected values obtained from the temperature functions have an uncertainty of ±0.10° C, and those from the salinity functions have an uncertainty of ±0.015‰ when samples are obtained twice weekly.

At Christmas Island temperatures are sampled daily rather than twice weekly as at Koko Head. In consequence, despite the larger variability, expected values obtained from the harmonic functions have approximately the same uncertainty as those obtained from the Koko Head harmonic functions. This statement is confirmed by considering the error terms that can be obtained by taking the difference of the expected values at the midpoint of the 30-day overlap portion of the Christmas Island temperature functions (see appendix D). On average this error term is 0.07° C and ranges from 0 to 0.26° C.

SOME PROPERTIES OF THE TEMPERATURE AND SALINITY DISTRIBUTIONS

Although the harmonic functions are merely analytic expressions of the temperature and salinity as a function of time, they do provide, to some extent, insight into the nature of the distributions. For instance, the monthly standard error of estimate, mentioned in the previous section, provides a measure of the month-to-month changes in variability. At Koko Head there is no seasonal pattern in this variability of the temperature; however, there is a seasonal pattern in the variability of the salinity. The monthly standard errors of estimate of the salinity function with harmonic analysis carried out to $n = 13$, are listed in Table 4.

TABLE 4.—Standard error of estimate (‰) for each month, 1956-68, of the Koko Head salinity. Harmonic analysis is carried out to $n = 13$.

	MONTH											
YEAR	1	2	3	4	5	6	7	8	9	10	11	12
1956	0.030	0.017	0.027	0.048	0.064	0.052	0.024	0.008	0.012	0.014	0.014	0.015
1957	0.049	0.013	0.021	0.015	0.030	0.034	0.029	0.017	0.036	0.031	0.018	0.034
1958	0.006	0.041	0.052	0.049	0.059	0.026	0.028	0.028	0.013	0.023	0.044	0.022
1959	0.049	0.035	0.044	0.136	0.040	0.036	0.054	0.023	0.047	0.032	0.023	0.035
1960	0.042	0.032	0.018	0.019	0.056	0.043	0.075	0.035	0.033	0.014	0.014	0.024
1961	0.036	0.019	0.017	0.019	0.027	0.054	0.011	0.020	0.025	0.021	0.023	0.023
1962	0.054	0.040	0.064	0.021	0.013	0.023	0.025	0.033	0.031	0.031	0.018	0.027
1963	0.029	0.026	0.018	0.073	0.045	0.036	0.021	0.025	0.020	0.022	0.032	0.036
1964	0.031	0.033	0.031	0.030	0.029	0.019	0.035	0.050	0.053	0.052	0.024	0.036
1965	0.044	0.053	0.059	0.092	0.032	0.043	0.034	0.016	0.018	0.033	0.019	0.019
1966	0.026	0.016	0.011	0.014	0.022	0.021	0.011	0.012	0.016	0.033	0.065	0.036
1967	0.026	0.029	0.097	0.055	0.050	0.015	0.019	0.021	0.017	0.031	0.029	0.056
1968	0.034	0.024	0.057	0.041	0.040	0.019	0.035	0.026	0.018	0.021	0.016	0.038

In each year excepting 1957, 1964, and 1966, highest variability occurred during the first 7 months of the year. In 1957 a seasonal pattern was not clearly apparent and in 1964 and 1966 highest variability occurred during the last 5 months of the year. Although the seasonal pattern of variability has not been examined in detail, it is consistent with the results of previous studies (Seckel, 1962, 1969). First, Hawaii is located in the vicinity of a relatively high salinity gradient that delineates the boundary of the North Pacific Central Water. Thus, the salinity measured at the Koko Head sampling station is sensitive to variations in the location of this water type boundary. Secondly, northward displacement of water (warm advection) tends to occur during the first 7 months of the year. In consequence the water type boundary that generally lies south of the Koko Head sampling station during autumn and winter is brought to within the vicinity of the sampling station. The months with higher variability tend to be associated with declines in the Koko Head salinity.

Insight into the nature of the distributions is also obtained by examining the spectra of the harmonic functions. It is evident from the figures in appendix B, that considerable temperature and salinity variability at Koko Head occurs with timespans of 35 to 60 days. Rather than showing the amplitudes for each harmonic of every function, the 13-year mean of the absolute magnitude of amplitudes for each harmonic of the Koko Head temperature and salinity functions is presented in Figure 2.

For both the temperature and the salinity, the amplitude of the annual cycle ($n = 1$) is largest. The amplitudes then decline rapidly with increasing harmonics to $n = 5$. In the case of the temperature, a slight increase in amplitude occurs at $n = 6$ and $n = 9$. Similar small increases in amplitudes occur in the case of the salinity at $n = 7$ and $n = 9$. The increased amplitudes at $n = 6$ and $n = 7$, resolving 60- and 52-day periods, reflect the climatic signals described by Seckel (1962, 1969). The increased amplitude at $n = 9$, resolving a 41-day period, reflects shorter term variability that may be due to large geostrophic eddies with dimensions near 200 km (Wyrtki, 1967) or eddying flow near the Hawaiian Islands.

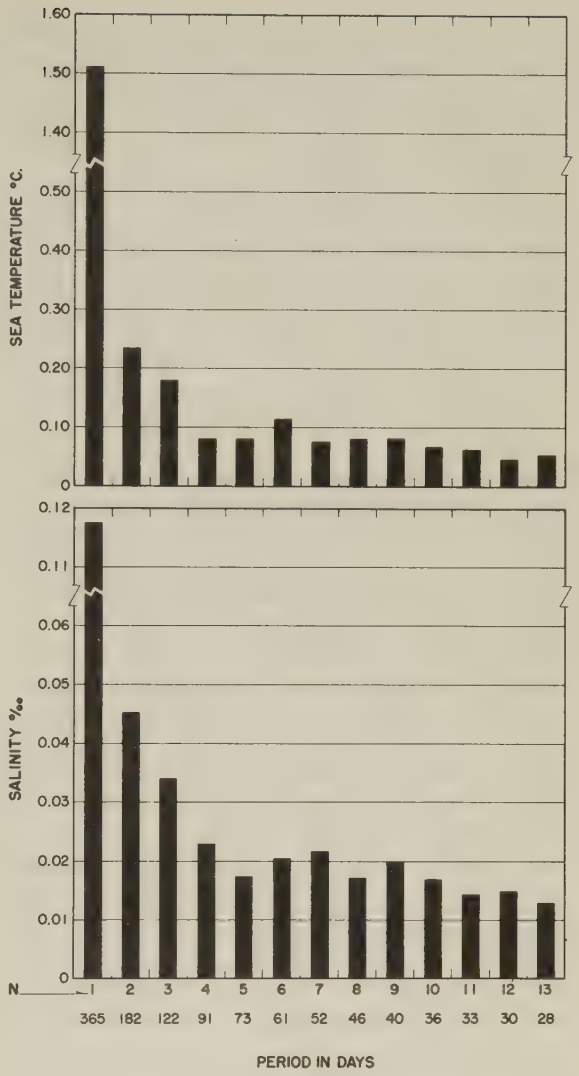


FIGURE 2.—Mean magnitude of amplitudes for each harmonic of the Koko Head temperature and salinity functions, 1956-69.

LONG-TERM HARMONIC FUNCTIONS

Long-term harmonic functions with the fundamental period spanning the entire duration of observations, can be obtained by the method described before in this paper. Temperatures and salinities were used as computed for the

1st and 16th of each month from the harmonic functions whose phase angles and coefficients are tabulated in appendixes A and C. Harmonic analysis was carried to $n = 42$ for the Koko Head temperature and salinity, and $n = 48$ for the Christmas Island temperature, giving in each case a 4 months' resolution. The fitted curves resulting from this analysis are shown in Figure 3, together with the values that were used as input data. Clearly the annual cycle forms the dominant signal in the Koko Head temperature curve. In the Koko Head salinity and Christmas Island temperature curves longer term changes are more pronounced than the annual cycle.

The relatively large deviations of the input data from the long-term function are to be expected. The figures of appendixes B and D show that variations with a duration of less than 4 months can be relatively large and are not resolved by the long-term analyses made.

The spectra of the long-term harmonic functions for the Koko Head temperatures and salinities and the Christmas Island temperatures are shown in Figure 4.

As is also apparent from Figure 3, the spectrum of the Koko Head temperature function is distinct from those of the Koko Head salinity and Christmas Island temperature functions. In the former the 12-month period has the most pronounced amplitude, but in the latter two, although the annual period has a large amplitude, the amplitudes of longer period changes are large and for some periods exceed those of the annual period.

CONCLUSION

The results of this paper show that sea-surface temperatures and salinities regularly monitored at island sampling stations can be expressed by harmonic functions of time. Advantages of analytic expressions for the temperature and salinity were cited in the introduction. Important applications will be in climatic oceanography where one may wish to filter out undesired "background noise." At Christmas Island, for example, the short-term variability with a duration of 1 month or less can be filtered out by using only the harmonic terms to $n = 3$ in the quarterly functions. At Koko Head, the variability with duration of less than 50 days, that may be due to large geostrophic or island-induced eddies, can be filtered out by using only the harmonic terms to $n = 7$ in the annual functions.

We mentioned in the introduction that the rates of change of temperature reflect the climatic processes of change and that distortions or aliasing may occur when monthly mean temperatures are used to compute the change of a property. Consider, for example, the Christmas Island temperatures from March to May 1968 (appendix D, days 61 to 152). In Table 5 are listed the monthly mean observed temperatures, the month-to-month changes of mean temperature, the expected temperatures from the harmonic functions for the 16th of each month (computed with harmonic terms up to $n = 4$), and the month-to-month changes of expected temperatures. It is clear from this illustration that the use of mean values would result in an underestimate of the rise in temperature from March to April, and would obscure the decline in temperature from April to May. The example is not isolated and other instances can be found in both the Koko Head and the Christmas Island data.

TABLE 5.—Month-to-month temperature differences using mean observed temperatures and expected temperatures from the harmonic function, Christmas Island, March to May 1968.

Date	Mean temperature	Change of mean temperature	Expected temperature	Change of expected temperature
	°C	°C	°C	°C
March 1968	25.1		25.1	
		0.9		1.2
April 1968	26.0		26.3	
		0.2		−0.3
May 1968	26.2		26.0	

The results also aid in the choice of an optimum sampling frequency. Both the desired confidence limit and the desired resolution must be considered. If the harmonic functions are to be used in monitoring the oceanographic climate as is the case of those presented in this paper, then the limits of about ±0.1° C for the expected temperature value and ±0.02‰ for the expected salinity value are adequate. As-

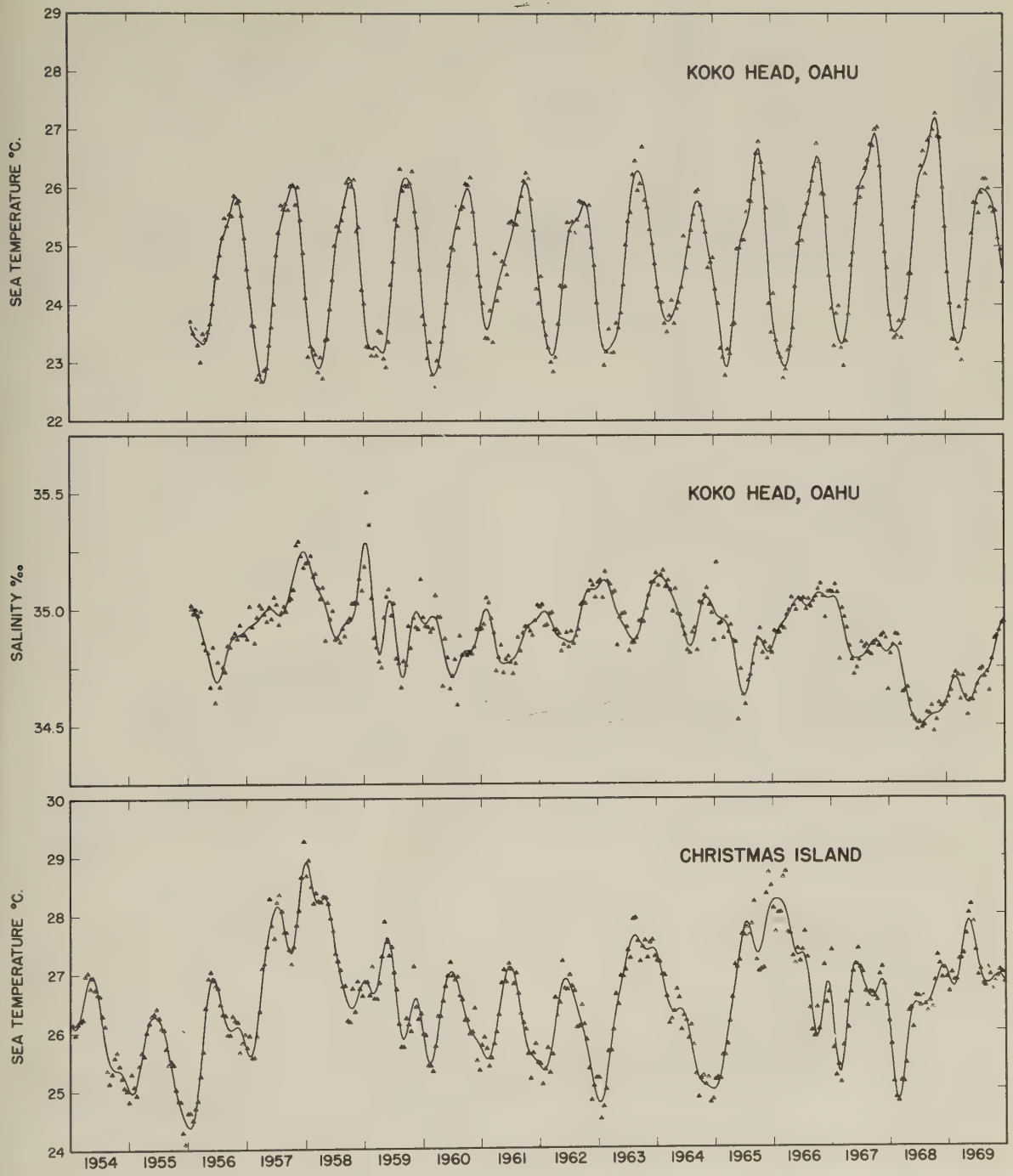


FIGURE 3.—Fitted curves with 4 months' resolution of the Koko Head temperature, 1956-69, Koko Head salinity, 1956-69, and the Christmas Island temperatures, 1954-69. Input data are indicated by small triangles.

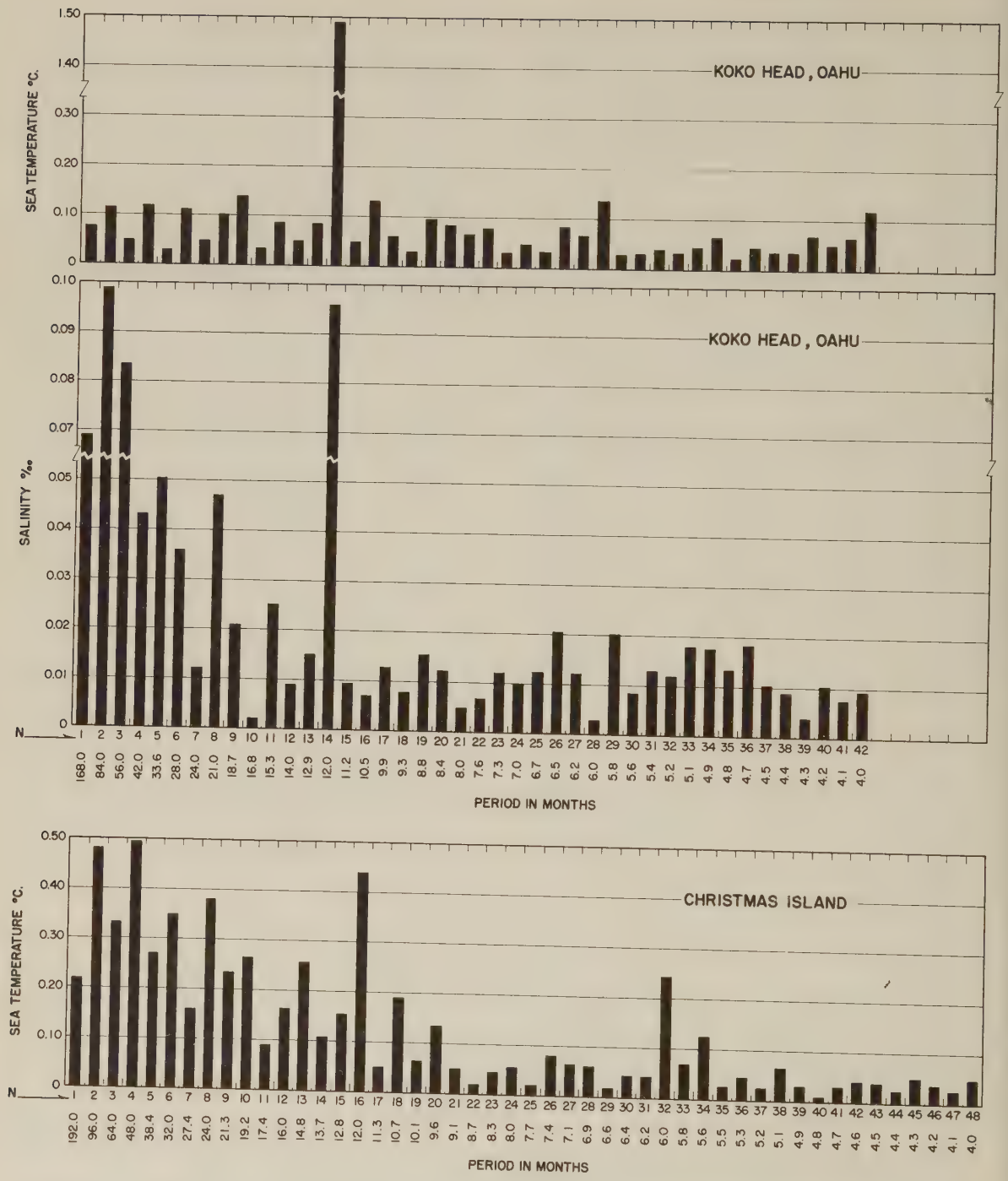


FIGURE 4.—Spectra of the long-term harmonic functions for Koko Head temperatures, 1956-69, Koko Head salinities, 1956-69, and Christmas Island temperatures, 1954-69.

suming that temperature and salinity samples are of Koko Head quality, then for a resolution of 1 month, weekly sampling is sufficient. Occasionally, however, a scheduled sample is not taken or an erroneous value must be eliminated. In such cases sampling gaps would become too large for the desired resolution. Undesirable sampling gaps can be avoided by doubling the minimum sampling frequency.

The simplicity and economy of deriving harmonic functions by computer are of practical value, particularly in the analysis of data sampled automatically. By this method large quantities of data can be brought into useful form rapidly.

The results of this paper, based on manual sampling, are useful in the investigations of changes with a duration of more than 1 month. Automated sampling would broaden the spectrum and permit analyses of shorter term variations such as diurnal changes, changes of tidal period, and other changes with durations of less than 1 month.

Automated sampling would also improve the quality of data since instruments can be placed in locations where undesirable variability is minimized and where manual sampling is difficult. At Koko Head, for example, samples are obtained from an exposed rock ledge where the island effects on the temperature and salinity are small. At Christmas Island, however, the sampling site is convenient and the best obtainable for manual sampling, but it is not the best in terms of monitoring open-ocean temperatures. This shortcoming is often also the case when temperatures and salinities are measured at tide stations located in protected bays or harbors.

The value of regularly monitoring the sea-surface temperatures and salinities has been demonstrated in many instances. For example, empirical relations between Koko Head temperatures and salinities and the availability of skipjack tuna to the Hawaiian fishery have been demonstrated (Seckel, 1963). Bjerknes (1969) has shown the relationship between anomalously high equatorial sea-surface temperatures using primarily Canton Island observations, and the intensification of the North Pacific westerlies and trades. This relationship must, in turn, affect temperatures and salinities in the North Pacific.

In view of these factors, serious consideration should be given to the establishment of automated sampling stations at selected islands in the Pacific. The derivation of harmonic functions, as demonstrated in this paper, would make reduction of data into usable form simple and economical and so facilitate the study of processes which govern the climate in both ocean and atmosphere.

LITERATURE CITED

Bjerknes, J.
1969. Atmospheric teleconnections from the equatorial Pacific. Mon. Weather Rev. 97(3): 163-172.

Holloway, J. Leith, Jr.
1958. Smoothing and filtering of time series and space fields. Advances in Geophysics 4: 351-389. Academic Press, New York.

Kaplan, Wilfred.
1953. Advanced calculus. Addison-Wesley Publishing, Cambridge, Mass., 679 pp.

Seckel, Gunter R.
1962. Atlas of the oceanographic climate of the Hawaiian Islands region. U.S. Fish Wildl. Serv., Fish. Bull. 61: 371-427.
1963. Climatic parameters and the Hawaiian skipjack fishery. *In* H. Rosa, Jr. (editor), Proc. World Sci. Meet. Biol. Tunas Related Species. FAO Fish. Rep. 6, 3: 1201-1208.
1969. The Hawaiian oceanographic climate, July 1963-June 1965. Bull. Jap. Soc. Fish. Oceanogr., Spec. No. (Prof. Uda's Commem. Pap.), pp. 105-114.

Seckel, Gunter R., and Kenneth D. Waldron.
1960. Oceanography and the Hawaiian skipjack fishery. Pac. Fisherman 58(3): 11-13.

Sokolnikoff, Ivan S.
1939. Advanced calculus. McGraw-Hill Book Co., New York and London, 446 pp.

Tabata, S.
1964. A study of the main physical factors governing the oceanographic conditions of station P in the northeast Pacific Ocean. D. Sc. thesis, Univ. Tokyo, 264 pp., 55 figs., 17 tables, 41 pp. appendixes.

Wyrtki, Klaus.
1967. The spectrum of ocean turbulence over distances between 40 and 1000 kilometers. Deut. Hydrog. Z. 20(4): 176-186.

APPENDIX A

Sea-surface temperatures and salinities, Koko Head, Oahu, 1956-69: Phase angles and coefficients for harmonic functions

$$S = K + bt + \sum_{n=1}^{k} C_n \cos\omega(nt - \alpha_n) ,$$

$$\omega = \frac{2\pi}{365} \text{ days}^{-1} ,$$

t is the time in days beginning with the first day in each year.

APPENDIX A TABLE 1.—Phase angles and coefficients for sea-surface temperatures, Koko Head, 1956-69.

	PHASE ANGLES IN DAYS												
	N-VALUES												
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13
1956	73.88	69.97	10.42	-49.85	52.41	-25.23	70.98	-87.01	-55.97	19.33	-75.22	-52.34	46.35
1957	76.76	-72.88	30.75	58.99	8.81	-38.20	35.79	73.88	47.14	15.87	-36.68	-16.51	-8.30
1958	62.38	-6.51	-54.94	48.26	-34.27	-45.62	-51.72	-71.25	-46.58	-51.12	-10.61	-2.52	3.53
1959	65.59	-49.40	8.61	-1.48	56.56	-5.01	-70.18	17.77	71.89	-16.60	-27.85	-66.12	-50.78
1960	64.16	74.63	-62.69	37.38	-23.54	16.29	-89.39	23.77	-52.95	32.76	54.93	24.86	74.57
1961	53.19	15.31	-22.50	7.72	39.01	16.65	-51.44	-67.83	-2.26	49.83	88.27	-35.38	27.19
1962	66.15	-74.11	80.89	66.44	-7.78	-13.61	51.28	88.26	20.81	-30.04	29.78	41.65	-26.88
1963	63.76	-68.73	38.52	-27.45	-63.66	79.24	70.43	8.76	27.22	18.36	-76.61	35.19	-25.46
1964	73.31	-23.47	15.92	-57.15	-83.11	54.99	61.66	54.83	48.58	-0.50	51.76	3.89	-85.70
1965	64.85	45.82	-83.31	81.93	40.40	87.16	1.79	4.19	-21.73	-57.28	58.34	27.01	-90.88
1966	72.24	85.17	-29.44	82.13	-85.83	10.42	8.38	31.25	-0.28	-55.09	-24.99	65.54	-64.62
1967	60.48	66.72	-70.68	-9.91	83.89	84.03	-81.16	69.38	-9.63	-62.49	-84.89	-59.30	61.41
1968	65.18	71.07	-5.56	-19.37	26.00	-1.69	9.55	-41.85	-4.66	70.29	32.63	-19.50	-50.35
1969	58.78	-16.32	-68.76	90.78	49.97	12.98	89.93	40.17	-0.78	43.89	-88.96	-54.80	76.11
MEAN	66.13	62.61	-34.59	-9.48	68.75	40.82	29.88	86.20	-16.08	23.05	79.63	19.30	-87.99

APPENDIX A TABLE 1.—Phase angles and coefficients for sea-surface temperatures, Koko Head, 1956-69.—*Continued.*

			AMPLITUDES												
			N-VALUES												
YEAR	K	b	1	2	3	4	5	6	7	8	9	10	11	12	13
1956	24.2857	0.0014	-1.1174	-0.1340	-0.1099	-0.0633	0.0255	-0.1008	-0.0407	0.0206	0.0575	0.0346	-0.0565	0.0313	-0.0228
1957	25.1584	-0.0039	-2.0983	0.3004	-0.2188	0.0195	-0.1006	-0.0499	-0.0256	-0.1151	-0.0761	-0.0508	0.0691	0.0278	0.0400
1958	24.2433	0.0011	-1.4988	-0.1047	-0.2459	-0.0062	-0.0965	0.0225	-0.0385	-0.0154	0.0513	0.1033	-0.0374	-0.0878	-0.0477
1959	24.3697	0.0008	-1.5707	-0.2354	-0.3358	0.0470	0.1414	-0.1173	-0.0240	0.0239	0.0798	0.0968	-0.0969	0.0389	-0.0391
1960	24.3239	0.0008	-1.4963	-0.1570	-0.1641	0.0825	0.0383	-0.0437	0.0810	-0.0558	0.1175	0.0393	0.0931	-0.0677	0.1034
1961	24.7453	0.0006	-1.0587	-0.4112	-0.1832	0.1314	0.0498	0.1401	-0.0574	0.1761	0.1798	0.1026	0.1073	-0.1105	-0.0403
1962	24.7987	-0.0014	-1.4437	0.2802	0.0761	0.0502	-0.1250	0.1465	0.0561	-0.0798	0.0590	-0.0587	0.0302	0.0352	0.1037
1963	24.3471	0.0019	-1.4430	-0.1124	-0.1025	0.0501	0.0916	-0.0979	0.1870	0.0645	-0.1092	-0.0450	-0.0409	0.0344	0.0424
1964	24.7972	-0.0008	-1.0946	-0.0931	0.0691	0.1611	-0.0573	-0.0956	-0.0675	-0.1461	0.0639	-0.1162	0.0872	-0.0194	-0.0702
1965	24.8006	-0.0003	-1.6891	-0.2896	-0.3339	0.1715	0.1857	0.2120	0.1332	0.1040	0.0290	0.0596	0.0518	-0.0716	0.0622
1966	25.0047	-0.0014	-1.9152	-0.4056	-0.0944	-0.1330	0.0300	-0.1687	0.0236	0.0548	0.0825	-0.0161	0.0254	-0.0170	0.0253
1967	25.2850	-0.0008	-1.8725	-0.2850	-0.3005	-0.1125	-0.0966	-0.2437	0.1082	-0.0694	0.0794	-0.0341	0.0586	0.0555	-0.0572
1968	24.8546	0.0028	-1.5364	-0.2820	-0.2155	-0.0568	-0.0194	-0.0275	0.1192	-0.1263	0.0787	-0.0445	-0.0137	0.0294	-0.0817
1969	24.7701	0.0003	-1.3374	0.2035	-0.0760	-0.1235	0.1544	0.1096	0.1056	-0.0626	0.0594	0.1396	-0.1064	-0.0373	-0.0016
MEAN	24.6989	0.0001	-1.5040	-0.1458	-0.1291	0.0147	0.0220	-0.0164	0.0215	-0.0335	0.0461	0.0098	0.0324	-0.0135	-0.0013

APPENDIX A TABLE 2.—Phase angles and coefficients for sea-surface salinities, Koko Head, 1956-69.

	PHASE ANGLES IN DAYS												
	N-VALUES												
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13
1956	-14.52	-68.27	-89.13	-4.08	52.05	15.36	16.54	-2.09	-40.95	62.40	24.44	-7.01	-8.85
1957	-25.52	67.90	6.11	22.47	4.85	-25.00	-8.60	-19.40	28.27	-82.38	73.57	83.14	34.59
1958	25.99	46.89	57.99	50.30	15.25	-88.16	17.82	-10.99	20.65	-34.78	43.80	-31.33	-5.52
1959	-57.46	-68.08	18.94	-71.46	59.29	-35.64	-64.98	-19.12	-72.96	71.02	3.20	-8.24	28.66
1960	15.99	-61.03	81.05	56.42	-14.00	43.21	-58.49	-64.87	-87.20	62.22	71.57	4.93	-16.77
1961	-17.27	48.97	45.52	-26.18	2.69	13.58	2.15	-50.58	-38.94	82.68	-85.76	70.83	72.92
1962	-37.91	35.77	-1.00	-88.77	23.96	-32.29	-56.02	43.47	21.90	-52.99	24.88	-39.69	0.0
1963	17.33	-33.19	-66.85	53.84	13.09	-61.03	86.91	-72.22	12.17	2.06	-56.52	27.79	-39.95
1964	28.39	-19.79	-82.91	-82.99	53.70	-69.42	55.05	51.23	-17.95	8.29	-67.42	-80.98	-1.92
1965	-39.50	1.54	-49.50	-29.90	-31.57	-81.95	9.24	1.57	-56.55	90.65	42.78	-22.53	9.48
1966	-51.26	10.69	59.98	14.96	-10.51	78.69	26.93	-21.00	-86.73	30.96	10.93	-40.71	64.32
1967	-50.66	-58.57	35.70	38.98	-76.06	-77.32	-70.26	-26.09	17.82	-57.29	-13.46	26.17	44.48
1968	12.29	85.76	80.38	-11.84	-1.90	-31.29	-19.27	-49.39	-5.37	43.75	-66.43	70.00	18.69
1969	-9.16	30.08	30.65	-63.98	-47.50	47.99	74.49	66.13	-85.89	48.21	84.68	-58.03	-60.81
MEAN	-11.17	47.12	63.72	46.06	26.70	29.49	39.79	-16.95	-79.12	-76.28	-75.40	13.10	-5.70

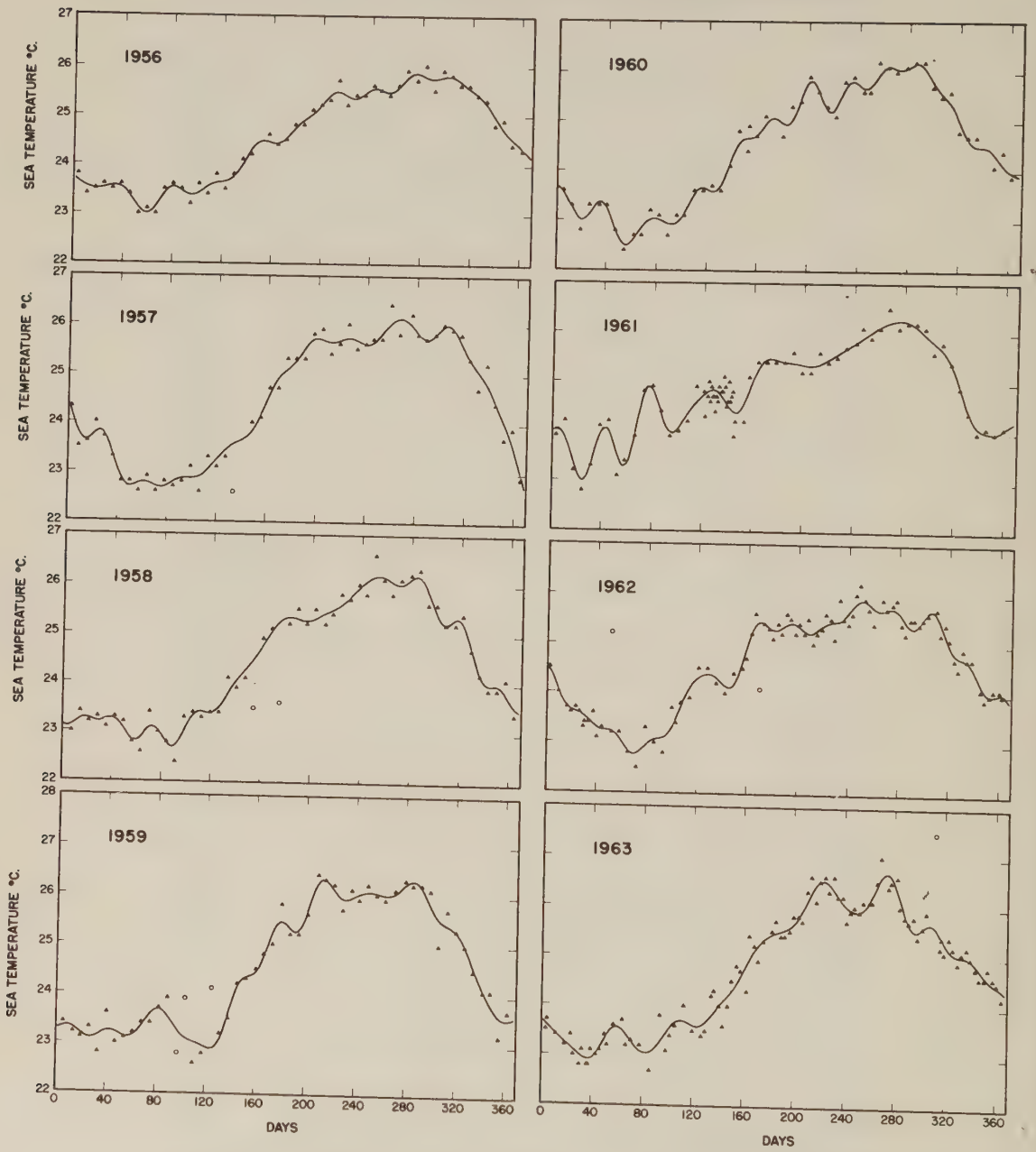
APPENDIX A TABLE 2.—Phase angles and coefficients for sea-surface salinities, Koko Head, 1956-69.—*Continued.*

			AMPLITUDES												
			N-VALUES												
YEAR	K	b	1	2	3	4	5	6	7	8	9	10	11	12	13
1956	34.8727	-0.0001	0.1261	-0.0420	-0.0164	-0.0071	0.0038	0.0099	0.0043	0.0167	-0.0176	-0.0258	0.0240	-0.0133	0.0270
1957	34.9345	0.0006	0.0604	-0.0544	-0.0305	-0.0029	0.0407	0.0242	0.0183	-0.0156	0.0195	-0.0079	-0.0127	0.0122	-0.0037
1958	34.9491	0.0004	0.1650	0.0324	0.0412	0.0088	0.0262	-0.0244	0.0063	0.0213	0.0244	-0.0130	-0.0292	0.0160	-0.0042
1959	35.2530	-0.0018	0.1996	0.2016	0.0884	0.0168	-0.0140	0.0120	-0.0272	-0.0340	-0.0271	0.0179	0.0254	-0.0191	0.0106
1960	34.8357	0.0000	0.1089	-0.0434	-0.0269	-0.0287	0.0239	0.0188	-0.0380	0.0378	-0.0373	-0.0198	-0.0187	0.0283	-0.0172
1961	34.8545	0.0001	0.1147	0.0368	0.0375	-0.0172	-0.0194	-0.0324	0.0162	-0.0191	-0.0179	-0.0177	0.0117	0.0064	-0.0151
1962	34.9396	0.0001	0.1084	-0.0230	-0.0116	0.0211	0.0035	0.0190	0.0254	0.0076	-0.0103	0.0106	-0.0051	0.0055	-0.0064
1963	34.9780	0.0001	0.1388	0.0067	-0.0164	-0.0371	0.0161	-0.0111	-0.0215	0.0162	0.0226	-0.0113	0.0197	0.0122	-0.0072
1964	34.9727	0.0001	0.1178	-0.0503	-0.0503	-0.0416	0.0209	-0.0158	0.0394	-0.0022	-0.0174	0.0316	-0.0025	-0.0142	0.0272
1965	34.9953	-0.0010	0.1566	-0.0564	0.0477	0.0412	0.0056	0.0163	0.0328	-0.0185	0.0356	0.0195	-0.0188	0.0331	0.0252
1966	34.8927	0.0006	-0.0401	-0.0131	0.0156	0.0271	0.0083	-0.0177	-0.0011	-0.0088	-0.0077	0.0161	0.0043	0.0084	-0.0114
1967	35.0184	-0.0009	0.1037	-0.0109	-0.0366	0.0248	-0.0310	-0.0417	-0.0368	-0.0184	-0.0169	0.0167	0.0091	0.0237	0.0179
1968	34.7135	-0.0006	0.1219	0.0424	0.0134	-0.0306	-0.0245	0.0191	0.0160	-0.0055	-0.0195	0.0044	0.0147	0.0050	-0.0022
1969	34.5912	0.0007	0.0821	0.0190	-0.0441	-0.0157	0.0044	-0.0243	-0.0200	0.0172	-0.0054	-0.0222	-0.0044	0.0103	0.0052
MEAN	34.9143	-0.0001	0.0972	-0.0051	0.0071	-0.0013	0.0064	0.0013	0.0070	-0.0026	-0.0065	0.0022	0.0073	0.0067	0.0040

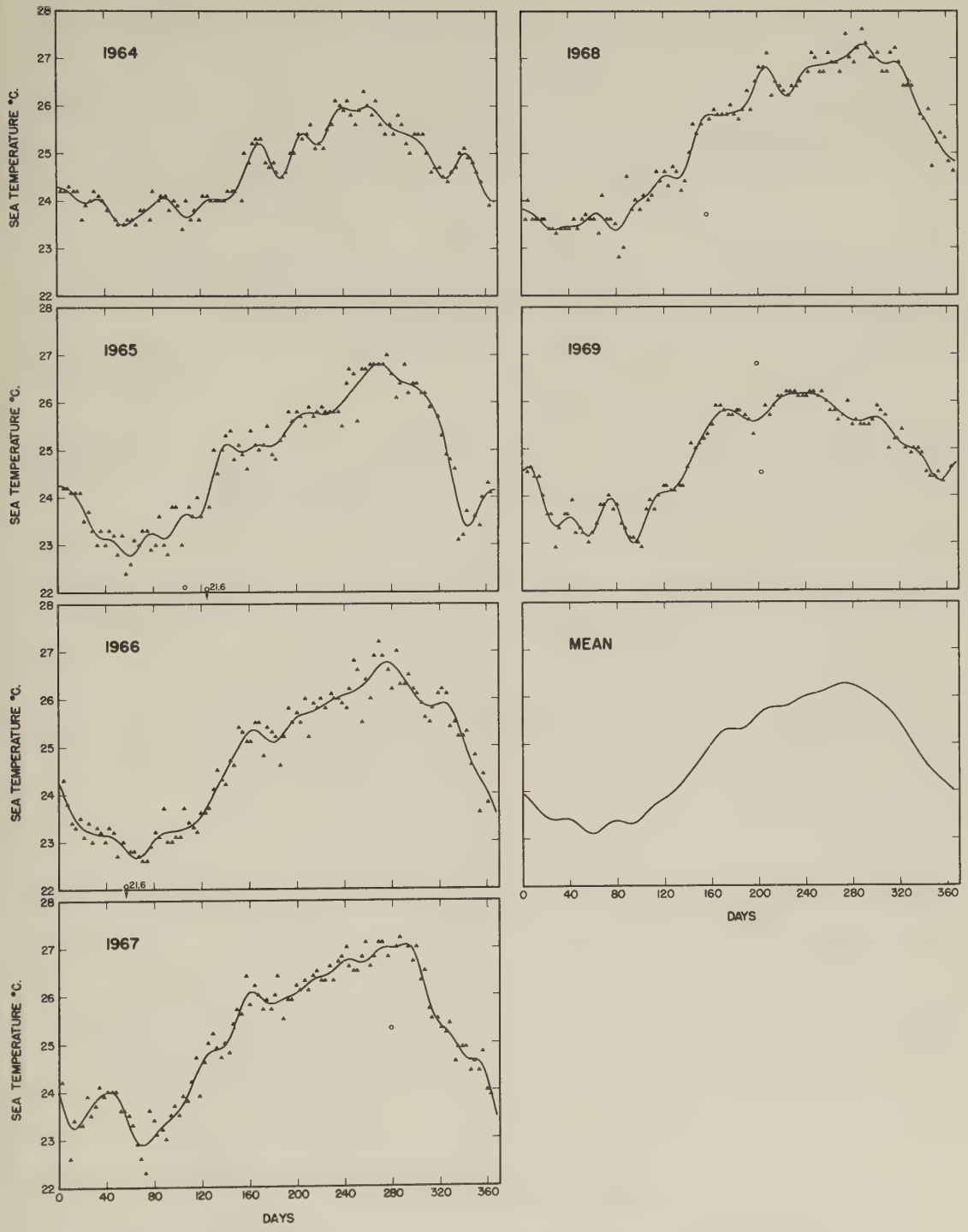
APPENDIX B

Sea-surface temperatures and salinities, Koko Head, Oahu, 1956-69: Fitted curves with observed values for each year.

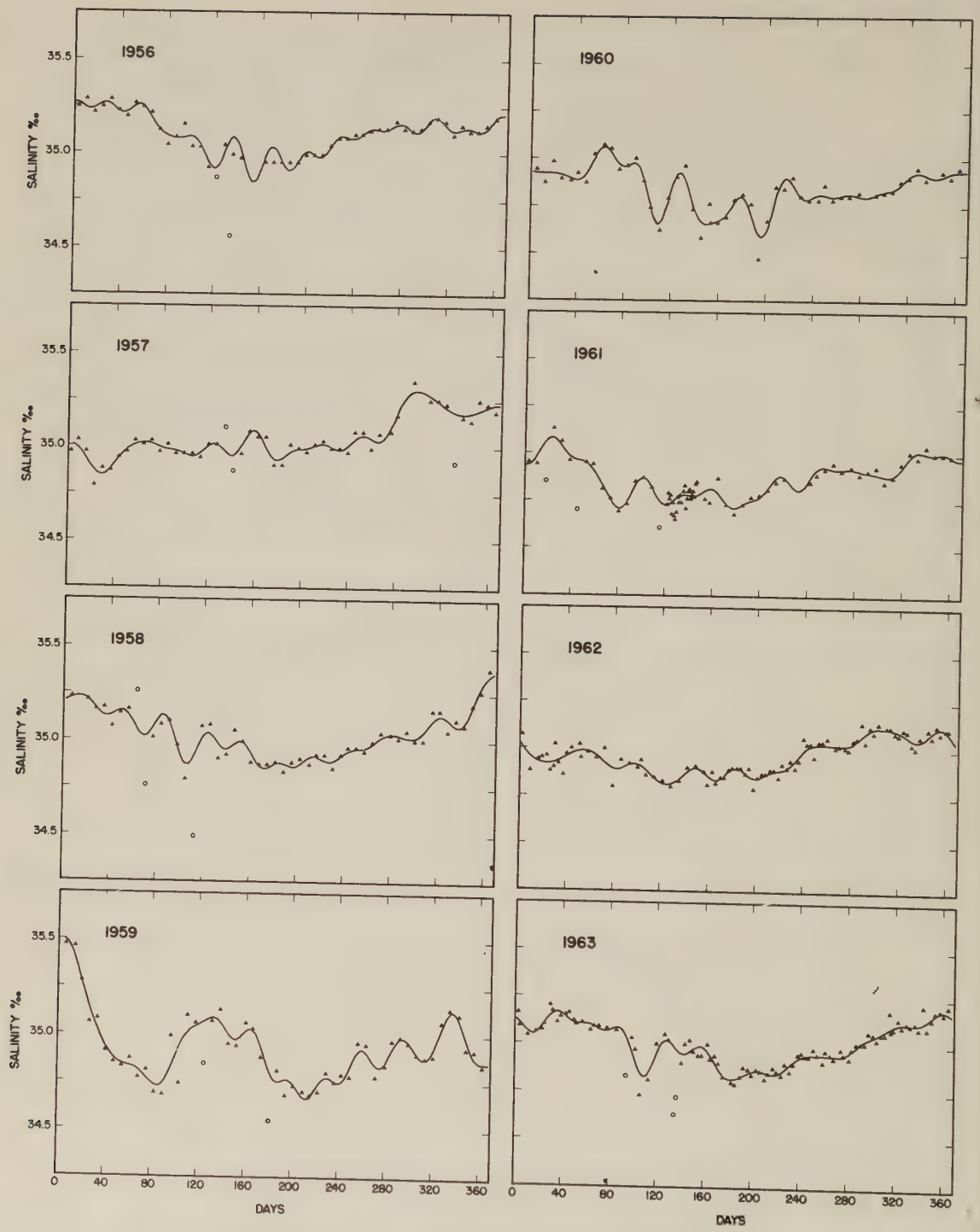
Note: Circled observations have not been used in the harmonic analysis.



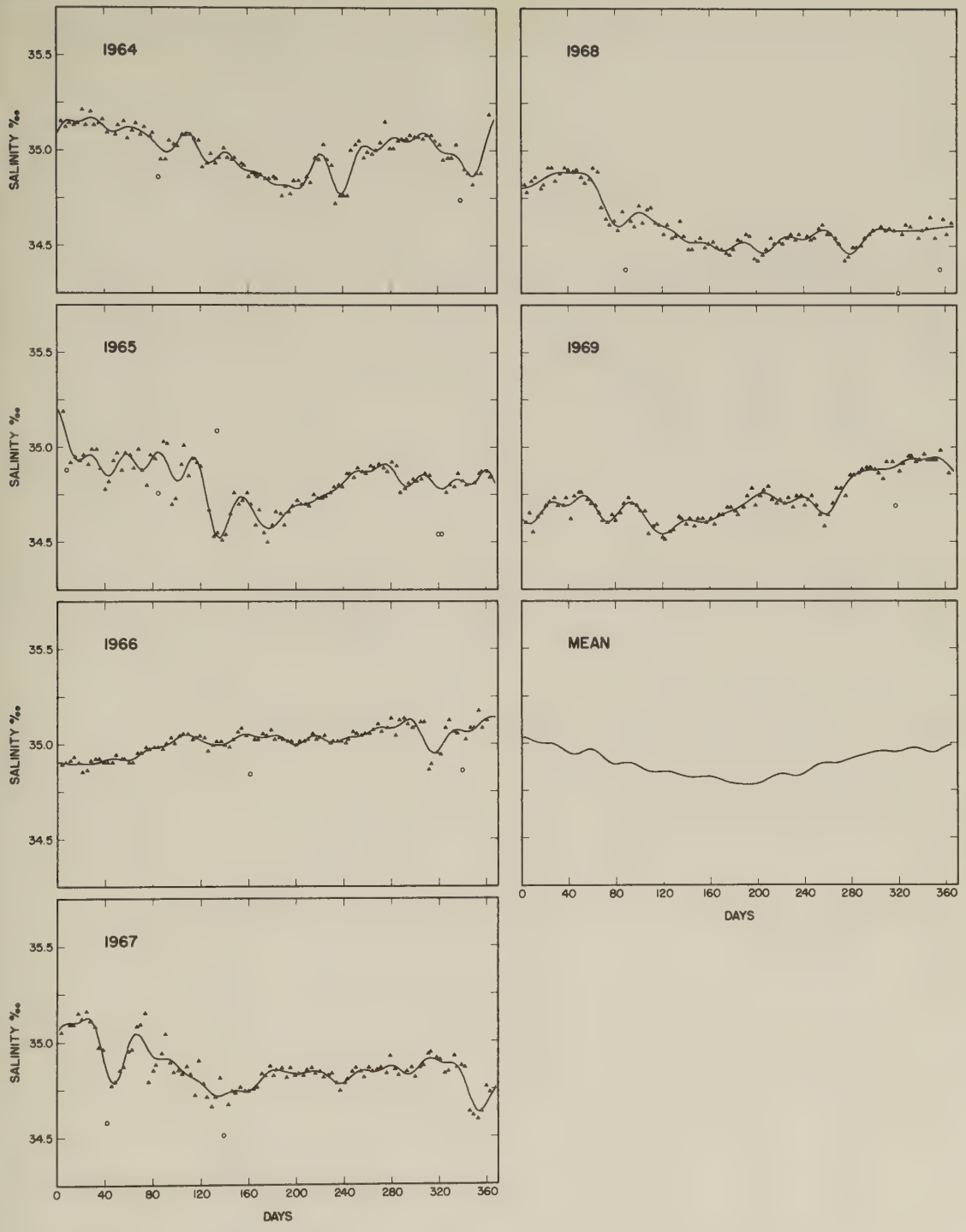
APPENDIX B FIGURE 1.—Sea-surface temperatures, Koko Head, 1956-69.



APPENDIX B FIGURE 1.—Sea-surface temperatures, Koko Head, 1956-69.—*Continued.*



APPENDIX B FIGURE 2.—Sea-surface salinities, Koko Head, 1956-69.



APPENDIX B FIGURE 2.—Sea-surface salinities, Koko Head, 1956-69—*Continued.*

APPENDIX C

Sea-surface temperatures, Christmas Island, 1954-69. Phase angles and coefficients for harmonic functions for each quarter of each year:

Days 1 to 120 = First quarter,
91 to 210 = Second quarter,
181 to 300 = Third quarter,
271 to 390 = Fourth quarter, extending 25 days into new year,

$$S = K + bt + \sum_{n=1}^{k} C_n \cos\omega(nt - \alpha_n) ,$$

$$\omega = \frac{2\pi}{120} \text{ days}^{-1} ,$$

t is the time in days beginning with the first day of each quarter.

Note: Mean values do not include phase angles and coefficients for the third and fourth quarters of 1967.

APPENDIX C TABLE 1.—Phase angles and coefficients for sea-surface temperatures, Christmas Island, 1954-69.

PHASE ANGLES IN DAYS

		N-VALUES						
YEAR	QU.	1	2	3	4	5	6	7
1954	1	29.96	-14.98	0.68	22.60	-16.29	0.45	-28.43
	2	21.92	24.40	-25.77	15.21	23.02	24.75	8.06
	3	-19.46	21.45	-25.73	-10.27	-14.81	-6.52	-20.70
	4	-15.22	27.64	6.23	-9.84	25.21	27.55	-26.39
1955	1	-25.04	-14.36	-19.66	-25.05	10.26	1.57	-17.43
	2	-1.34	-22.96	16.15	-12.62	-27.83	-6.10	24.53
	3	-28.76	23.27	29.69	-21.77	-18.26	28.12	10.11
	4	-5.04	-11.73	-11.08	5.52	9.94	-2.89	-1.09
1956	1	-15.33	29.40	18.77	24.08	27.16	17.61	-20.53
	2	25.55	29.94	-23.88	27.18	-22.20	-10.40	-16.16
	3	-26.54	21.39	-22.54	13.46	20.29	29.39	-17.29
	4	-28.99	16.56	-15.87	-0.61	6.14	-27.68	1.48
1957	1	-20.33	9.65	-3.33	-13.39	-22.18	24.07	4.11
	2	12.45	3.80	-21.56	22.60	5.19	18.04	16.55
	3	12.50	-8.47	27.08	22.42	5.63	4.72	-24.37
	4	1.99	-11.91	-1.14	15.68	5.08	-17.77	-21.22
1958	1	-15.56	-9.55	16.21	-19.82	-16.02	-9.08	8.91
	2	-25.92	-8.31	-7.41	26.09	-26.16	-28.63	17.52
	3	17.11	-4.98	25.83	9.96	6.39	-15.05	-24.35
	4	-25.45	16.23	-11.73	19.38	7.25	16.83	20.96
1959	1	-11.25	18.21	25.30	27.40	2.42	-3.45	-27.76
	2	-4.58	-18.05	-2.17	-6.57	15.76	-29.98	28.66
	3	-13.92	-7.90	26.00	-0.14	15.14	3.09	21.42
	4	-25.63	-23.22	-13.08	18.13	-10.51	-22.26	28.72
1960	1	-21.36	3.16	-22.67	15.60	-1.99	22.75	21.91
	2	14.95	-26.09	18.68	6.43	23.12	-22.78	28.33
	3	21.14	17.18	10.04	7.87	6.28	20.84	-2.55
	4	-0.89	0.26	-28.94	9.46	17.99	23.48	-26.06
1961	1	-4.50	2.29	14.03	9.01	9.50	-26.75	14.56
	2	-9.38	-18.74	15.60	10.81	5.59	-18.31	-27.53
	3	-27.87	-27.65	27.26	26.89	21.47	-10.55	-13.26
	4	-19.95	-17.14	-3.05	0.39	-13.80	-7.92	24.95
1962	1	10.13	-24.96	-16.24	29.64	4.40	16.34	-1.98
	2	-10.33	-1.79	27.51	28.58	-0.81	8.88	-15.25
	3	18.78	20.95	-6.12	-29.13	-2.99	-1.52	2.56
	4	29.70	7.75	14.37	-13.15	-25.15	-4.47	13.65
1963	1	18.62	14.96	21.66	21.78	-21.72	-8.72	-19.16
	2	-25.86	-23.08	-21.84	-25.95	-12.90	-7.23	-3.15
	3	27.97	-11.92	17.92	-10.01	20.37	-9.25	15.06
	4	5.53	-27.74	-4.23	12.23	13.77	6.00	-14.49
1964	1	10.51	23.82	-4.95	-11.60	-22.13	13.52	9.47
	2	29.78	-24.66	11.64	-19.75	22.21	-13.85	-22.39
	3	3.66	-21.54	13.24	5.89	-17.78	16.09	6.84
	4	9.57	-19.61	-22.27	-11.16	-12.19	-18.46	-4.51
1965	1	-12.81	22.40	-29.54	24.56	25.12	16.28	-23.00
	2	-16.03	-23.97	-7.39	-19.45	2.93	-11.03	1.10
	3	28.09	-13.92	12.10	-9.87	6.09	14.42	-23.32
	4	-10.42	20.99	27.57	29.48	-18.90	17.82	-18.83
1966	1	-2.72	-22.51	-8.68	9.75	-10.62	-6.62	29.58
	2	29.77	26.12	4.26	21.28	15.28	27.61	-22.03
	3	7.34	25.04	9.12	25.58	1.93	10.76	4.92
	4	8.34	0.12	-20.67	1.80	-28.17	3.39	26.99
1967	1	-22.45	14.34	-25.09	18.95	0.56	10.45	-20.67
	2	-8.36	-8.88	-1.88	-22.37	-24.08	16.60	21.27
	3	-29.90	-2.24	18.31	26.99	-16.01	9.55	-12.24
	4	-19.32	23.12	7.45	-6.85	-19.61	7.19	8.69
1968	1	-9.18	-10.65	23.64	-20.93	11.66	-20.43	-24.40
	2	-14.96	-23.53	13.31	-14.18	7.83	27.96	20.00
	3	-0.07	-22.76	5.17	5.55	-23.92	-10.81	-2.39
	4	27.65	-15.84	3.23	-21.90	-10.88	-24.36	6.48
1969	1	13.34	14.46	6.54	-17.39	7.54	6.63	-7.29
	2	8.02	-23.81	-20.76	26.56	-28.81	29.11	27.75
	3	22.54	11.28	11.96	25.05	-8.17	12.69	28.92
	4	-24.65	-0.88	-15.33	-12.66	-11.06	-13.66	4.95
MEAN	1	-14.97	-10.80	-22.92	-20.97	16.82	20.22	20.72
	2	9.25	11.74	20.56	15.71	28.30	-19.45	-9.57
	3	5.57	22.63	15.62	14.65	25.53	22.30	-25.12
	4	-4.77	-2.64	-27.75	-26.43	20.79	-26.95	10.88

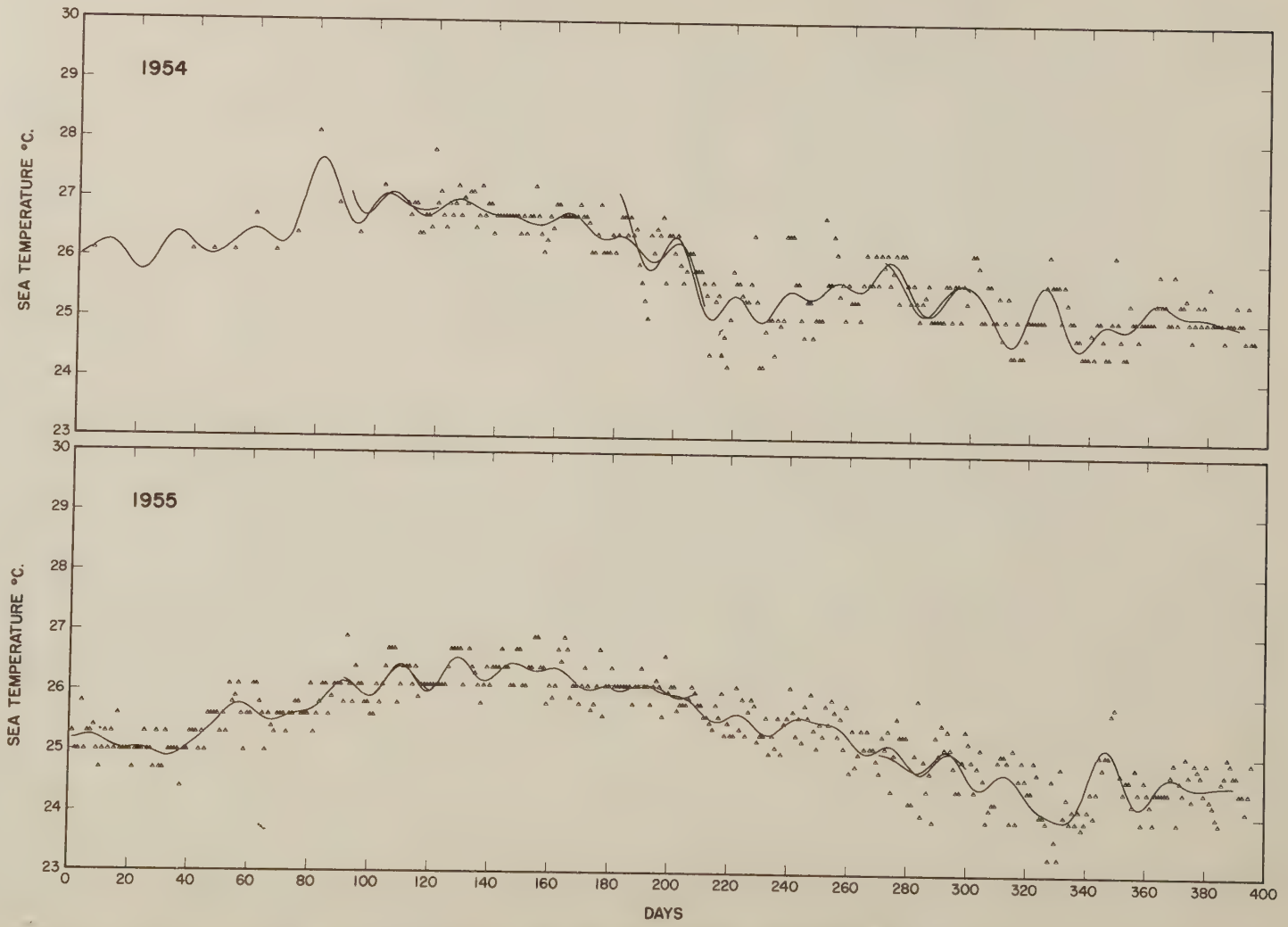
APPENDIX C TABLE 1.—Phase angles and coefficients for sea-surface temperatures, Christmas Island, 1954-69—*Continued.*

				AMPLITUDES						
				N-VALUES						
YEAR	QU.	K	b	1	2	3	4	5	6	7
1954	1	26.0740	0.0070	-0.2543	-0.1310	0.1609	-0.0772	-0.2829	0.0637	0.0743
	2	27.5957	-0.0169	-0.3583	-0.1443	0.1307	-0.1171	-0.1275	-0.1517	-0.0342
	3	26.4268	-0.0139	0.6131	0.0815	-0.0171	0.1382	0.2404	0.1808	-0.1111
	4	25.6919	-0.0090	0.2918	-0.1571	-0.0880	0.2517	0.1746	-0.1001	-0.0948
1955	1	25.1633	0.0067	0.2697	0.1614	-0.0873	0.1008	-0.0360	-0.0632	-0.0698
	2	26.2916	-0.0017	-0.1687	0.0292	-0.0565	-0.0347	0.0635	0.1000	0.1044
	3	26.1027	-0.0107	-0.0046	0.1350	-0.0375	-0.0218	0.0853	-0.0284	-0.0917
	4	24.8187	-0.0041	0.2259	-0.1449	0.1578	-0.1789	0.1836	0.0816	-0.0946
1956	1	24.3949	0.0183	0.4678	-0.1493	-0.0999	0.1311	-0.1107	-0.0674	0.0277
	2	27.7890	-0.0174	-0.4323	-0.2228	0.1648	-0.1209	0.1879	0.0861	0.0232
	3	27.0093	-0.0139	0.5433	-0.1689	0.1687	-0.1784	-0.1535	0.1829	0.0787
	4	26.1278	-0.0049	0.1022	0.0890	-0.1479	-0.0249	-0.0544	0.2481	-0.0168
1957	1	25.4577	0.0176	0.3612	0.1892	0.1458	0.1574	0.1045	0.0540	0.0693
	2	27.7558	0.0025	-0.2169	-0.4098	0.1621	-0.0802	-0.1359	0.2288	-0.1088
	3	27.6226	0.0008	0.4254	0.0970	0.0939	-0.1184	-0.2340	-0.1508	-0.1202
	4	28.0288	0.0066	-0.5153	0.0870	-0.2655	-0.1550	0.0453	0.2115	0.1495
1958	1	28.6567	-0.0050	0.1989	0.1052	0.0983	0.0407	0.0531	-0.0732	-0.0469
	2	28.2124	-0.0091	-0.2768	-0.0700	-0.0795	-0.0835	-0.1346	-0.0783	0.1074
	3	26.6129	0.0	0.3456	-0.1571	0.2536	0.0694	-0.1207	0.0260	0.0474
	4	26.2684	0.0066	-0.2862	0.0679	0.1955	0.1226	0.0867	-0.0855	0.0184
1959	1	26.8512	0.0025	0.3797	-0.3106	-0.2379	-0.1429	0.0562	-0.0545	0.0838
	2	27.8849	-0.0132	-0.2731	-0.1508	-0.1839	-0.1429	-0.0674	-0.0819	0.0641
	3	26.3895	-0.0025	0.5706	0.4088	-0.2084	-0.1502	-0.1315	-0.0472	-0.0216
	4	26.7237	-0.0091	-0.1536	-0.2531	-0.2372	-0.2151	0.1113	0.1418	-0.0299
1960	1	25.6504	0.0042	0.4722	0.0679	0.1461	0.1082	0.0721	-0.0691	0.0460
	2	26.9858	-0.0025	-0.3299	0.1787	-0.1260	-0.0797	0.0321	-0.0404	-0.0377
	3	26.5916	-0.0033	0.3107	0.1345	0.1430	-0.1676	-0.0941	0.0284	-0.0720
	4	26.0923	-0.0049	0.1670	-0.3080	0.1905	-0.1680	-0.0272	-0.1538	-0.1171
1961	1	25.3508	0.0109	0.3816	0.1665	0.0125	-0.1322	-0.1105	0.1068	0.1995
	2	26.7608	0.0025	-0.1900	-0.0611	-0.1699	-0.2098	0.1176	0.0254	0.0986
	3	26.5390	-0.0066	-0.4129	-0.2944	0.0796	0.0568	-0.1021	-0.1658	-0.0319
	4	25.3383	0.0016	-0.2387	0.1069	0.1592	-0.0197	0.1122	0.0896	0.0918
1962	1	24.9107	0.0168	0.1042	-0.2920	0.2226	0.0317	0.0329	0.1702	-0.0358
	2	26.5159	0.0033	-0.2921	-0.2701	-0.1616	0.1077	-0.0996	-0.1532	0.1131
	3	26.9093	-0.0139	-0.2714	0.1472	-0.1661	-0.0770	0.0532	0.0728	-0.0359
	4	25.6078	-0.0090	-0.2539	0.2136	0.0877	0.0963	-0.0275	-0.0509	-0.0641
1963	1	24.5106	0.0202	-0.1137	-0.0707	0.1670	0.0588	0.1332	-0.0370	-0.2257
	2	27.3700	-0.0033	0.5749	0.3627	0.3065	0.1391	0.1594	0.0779	0.2440
	3	27.2705	0.0041	0.3865	-0.2983	0.0802	-0.1328	0.1014	0.1157	-0.0641
	4	27.6762	-0.0066	-0.0697	0.1280	0.0933	0.1408	0.0886	0.0388	0.0603
1964	1	26.7596	-0.0025	0.4138	-0.0692	0.0988	0.1046	-0.0882	-0.0860	-0.0658
	2	26.2958	-0.0017	0.2579	-0.2425	-0.1394	0.0522	0.1147	0.0422	-0.0869
	3	26.0159	-0.0092	0.4285	-0.1814	0.1304	-0.0741	0.1106	0.0733	-0.1184
	4	24.8755	0.0033	0.1803	-0.1368	0.0999	0.1655	-0.0848	0.0989	-0.0299
1965	1	25.0849	0.0151	0.2248	-0.1215	0.0998	-0.0676	-0.1001	0.0939	-0.0430
	2	26.4776	0.0149	-0.2682	-0.2288	-0.1801	-0.0793	-0.0111	0.0295	-0.0471
	3	27.2809	0.0033	0.6393	0.1140	0.3702	0.2312	-0.2351	0.1376	-0.0732
	4	27.3759	0.0098	-0.7293	-0.2572	-0.0559	-0.1109	0.0830	-0.0606	-0.0654
1966	1	28.3584	-0.0076	-0.5145	0.1954	-0.2585	0.0741	-0.1413	0.1728	0.1227
	2	28.5148	-0.0198	-0.8788	-0.3261	0.0899	-0.0254	-0.0921	-0.1870	0.0975
	3	26.6145	-0.0041	0.4308	0.4345	0.2067	0.2310	0.2313	0.0932	0.1898
	4	27.2510	-0.0164	-0.8011	-0.0462	0.6174	0.1390	-0.1069	-0.0289	-0.2482
1967	1	25.3932	0.0076	0.3944	0.1627	0.2864	-0.0779	0.0240	-0.1438	0.0926
	2	26.4576	0.0066	-0.5433	-0.1618	-0.1932	-0.0712	-0.0620	0.0473	0.0553
	3	26.8336	-0.0044	0.1341	0.1093	0.0717	0.0649	-0.0896	-0.0822	0.0505
	4	27.8062	-0.0233	-0.0832	0.0851	0.0784	0.0593	0.0301	0.0046	0.0312
1968	1	25.1250	0.0033	0.5597	0.2691	-0.1413	0.2029	0.0708	0.0239	0.0730
	2	25.9567	0.0066	-0.1308	-0.1705	-0.2038	0.0706	0.0276	-0.1003	0.0172
	3	26.2971	0.0057	0.3013	0.0743	-0.1219	0.2030	0.1886	-0.2381	0.2042
	4	26.9967	0.0	0.1068	-0.0967	-0.1344	0.1499	-0.1181	-0.1165	0.0213
1969	1	26.4649	0.0168	0.1895	0.1321	-0.0869	-0.1854	0.0663	-0.0638	0.0926
	2	28.5357	-0.0165	-0.2815	0.3460	0.1314	-0.1603	0.1393	-0.1347	-0.1080
	3	27.0045	-0.0025	-0.0625	0.1304	-0.0853	-0.1166	-0.0388	0.1949	0.0671
	4	26.4789	0.0074	-0.2169	-0.0886	-0.1190	-0.1058	-0.1537	-0.0858	-0.0390
MEAN	1	25.8878	0.0082	0.2151	0.0484	0.0522	0.0285	-0.0074	-0.0107	0.0132
	2	27.2124	-0.0041	-0.1744	-0.0779	-0.0930	-0.0509	-0.0233	0.0283	0.0229
	3	26.7124	-0.0044	0.1770	0.0789	0.0498	-0.0071	-0.0629	0.0384	-0.0094
	4	26.3568	-0.0019	-0.0997	-0.0317	0.0509	0.0459	0.0341	0.0573	-0.0145

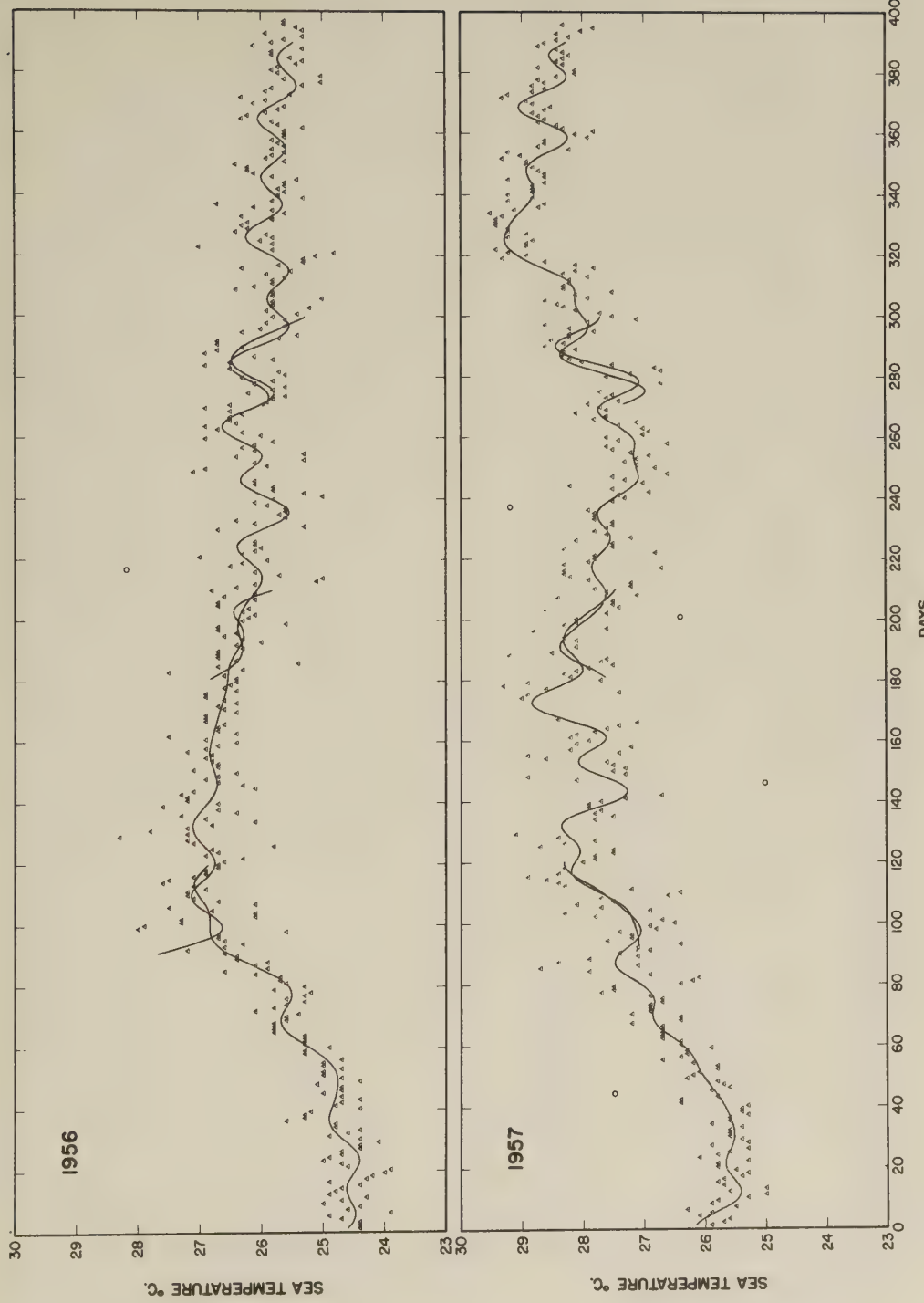
APPENDIX D

Sea-surface temperatures, Christmas Island, 1954-69: Fitted curves with observed values for each year.

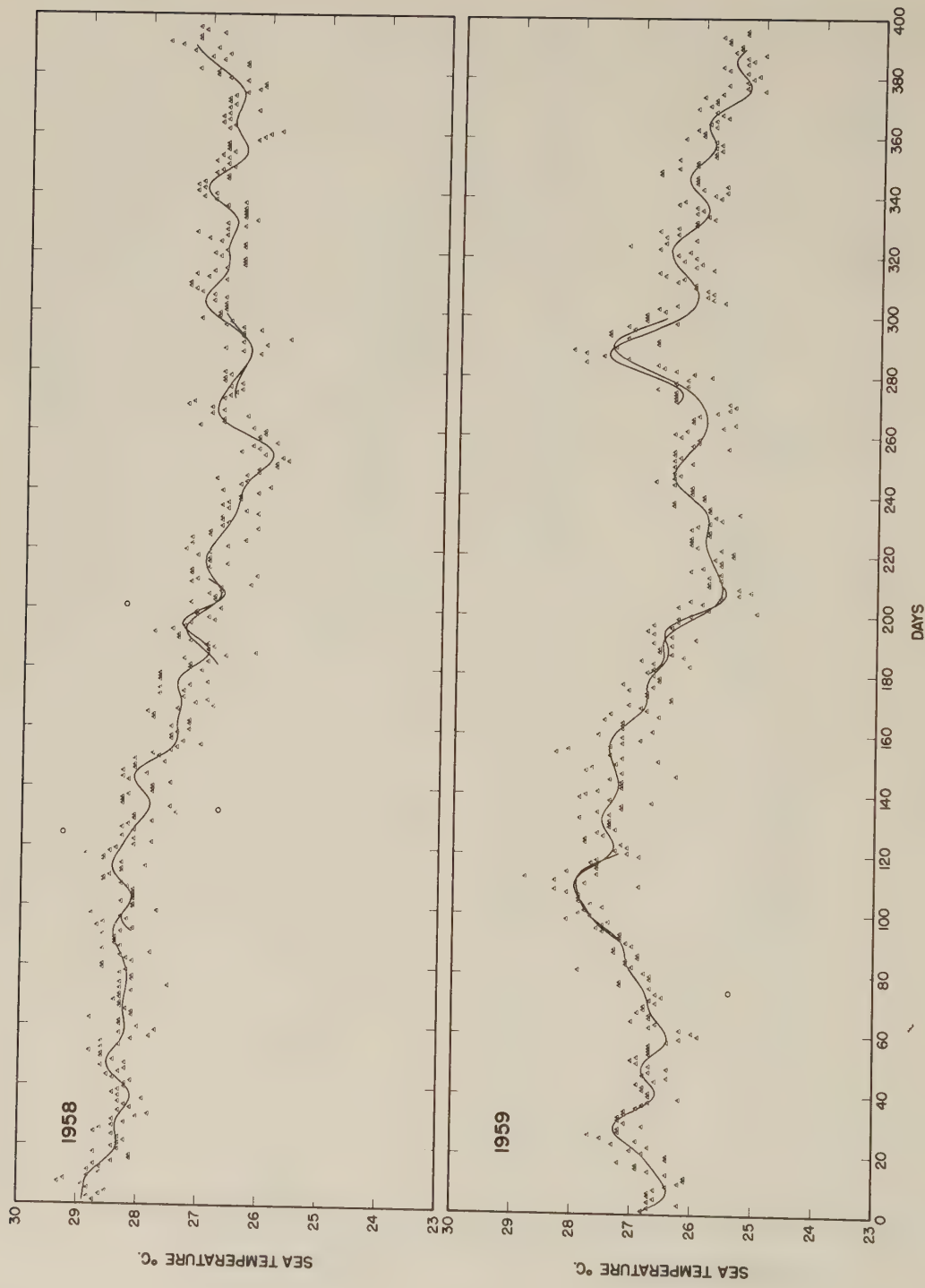
Note: Circled observations have not been used in the harmonic analysis.



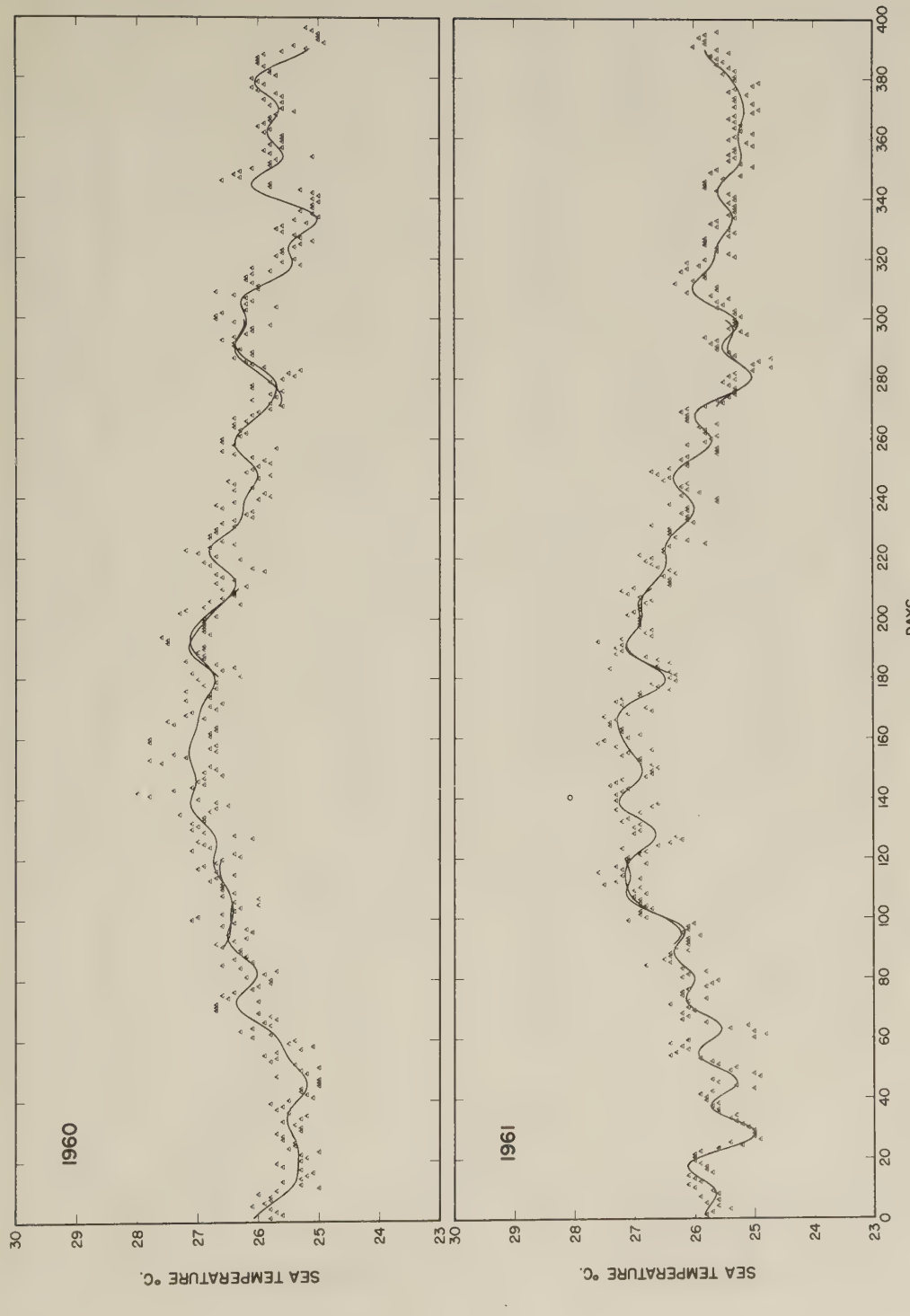
APPENDIX D FIGURE 1.—Sea-surface temperatures, Christmas Island, 1954-69.



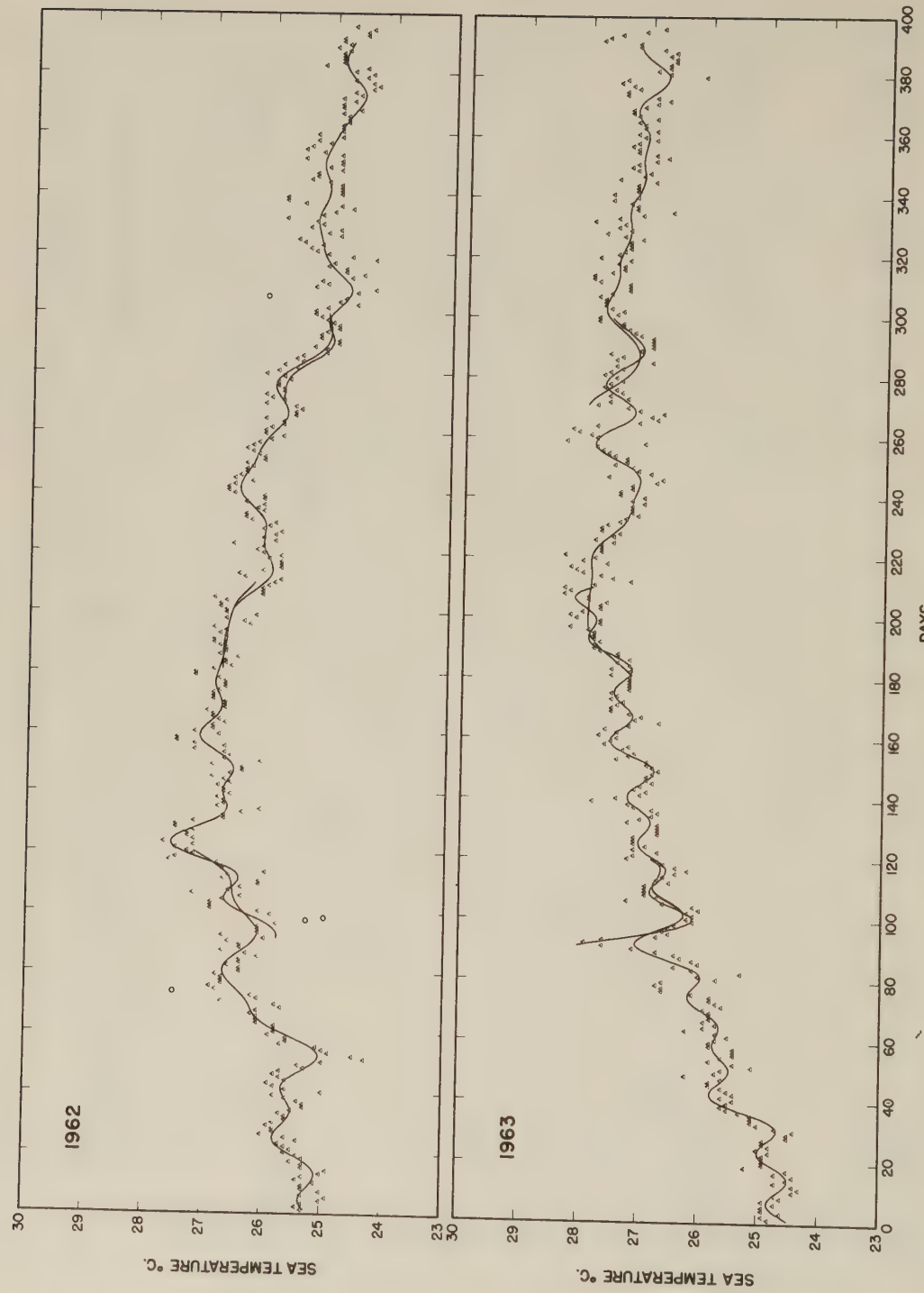
APPENDIX D FIGURE 1.—Sea-surface temperatures, Christmas Island, 1954-69.—*Continued.*



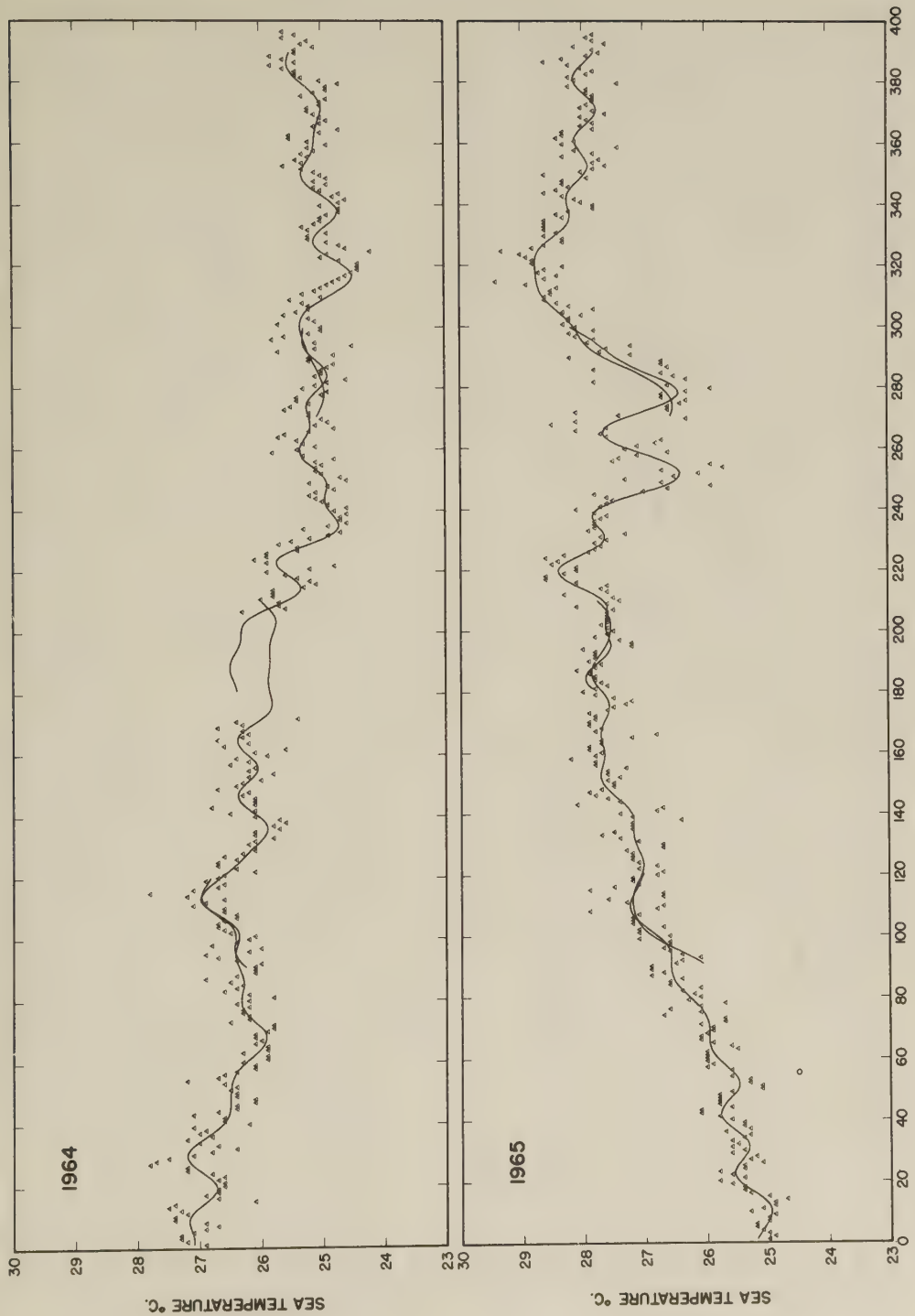
APPENDIX D FIGURE 1.—Sea-surface temperatures, Christmas Island, 1954-69.—*Continued.*



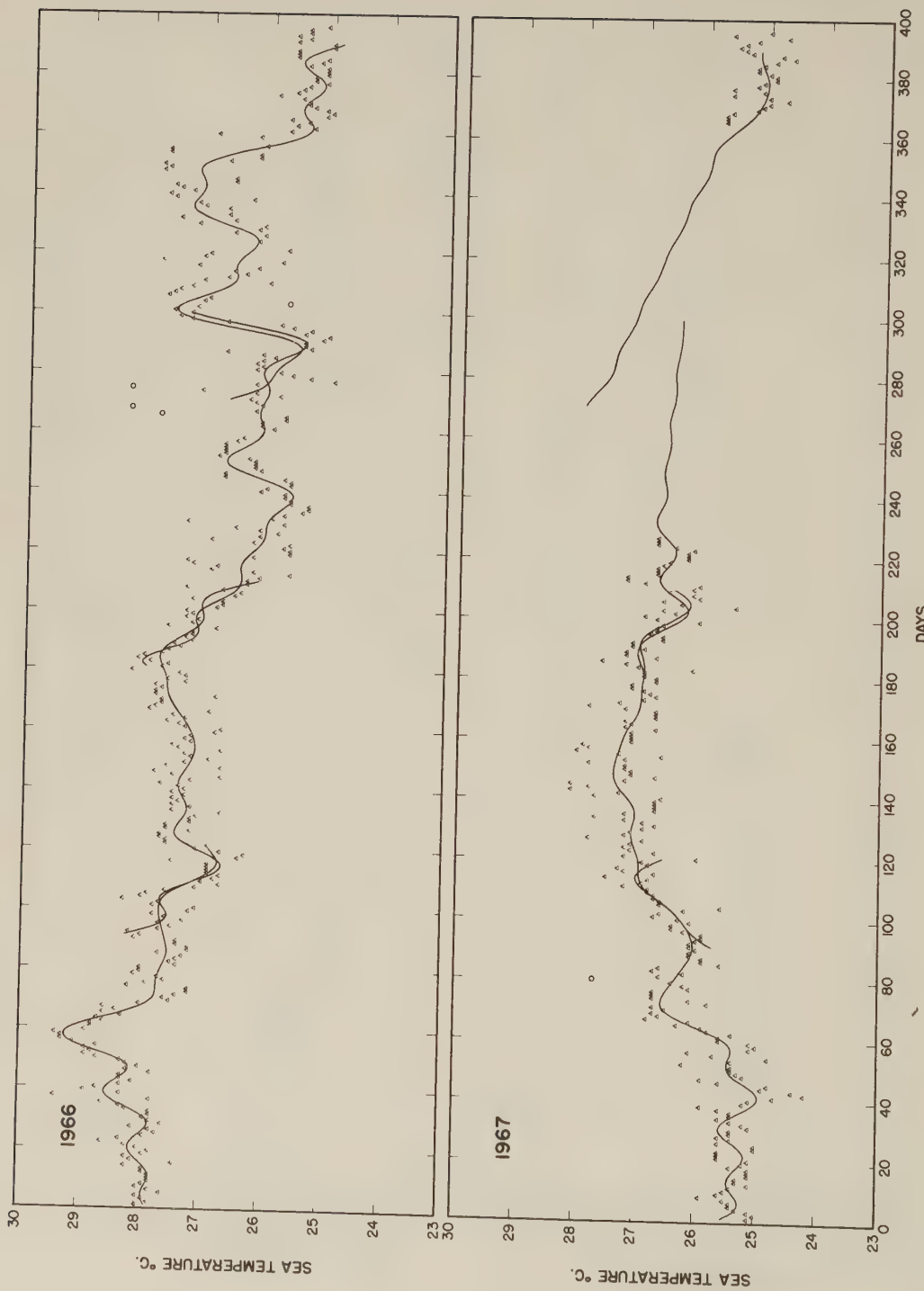
APPENDIX D FIGURE 1.—Sea-surface temperatures, Christmas Island, 1954-69.—*Continued.*



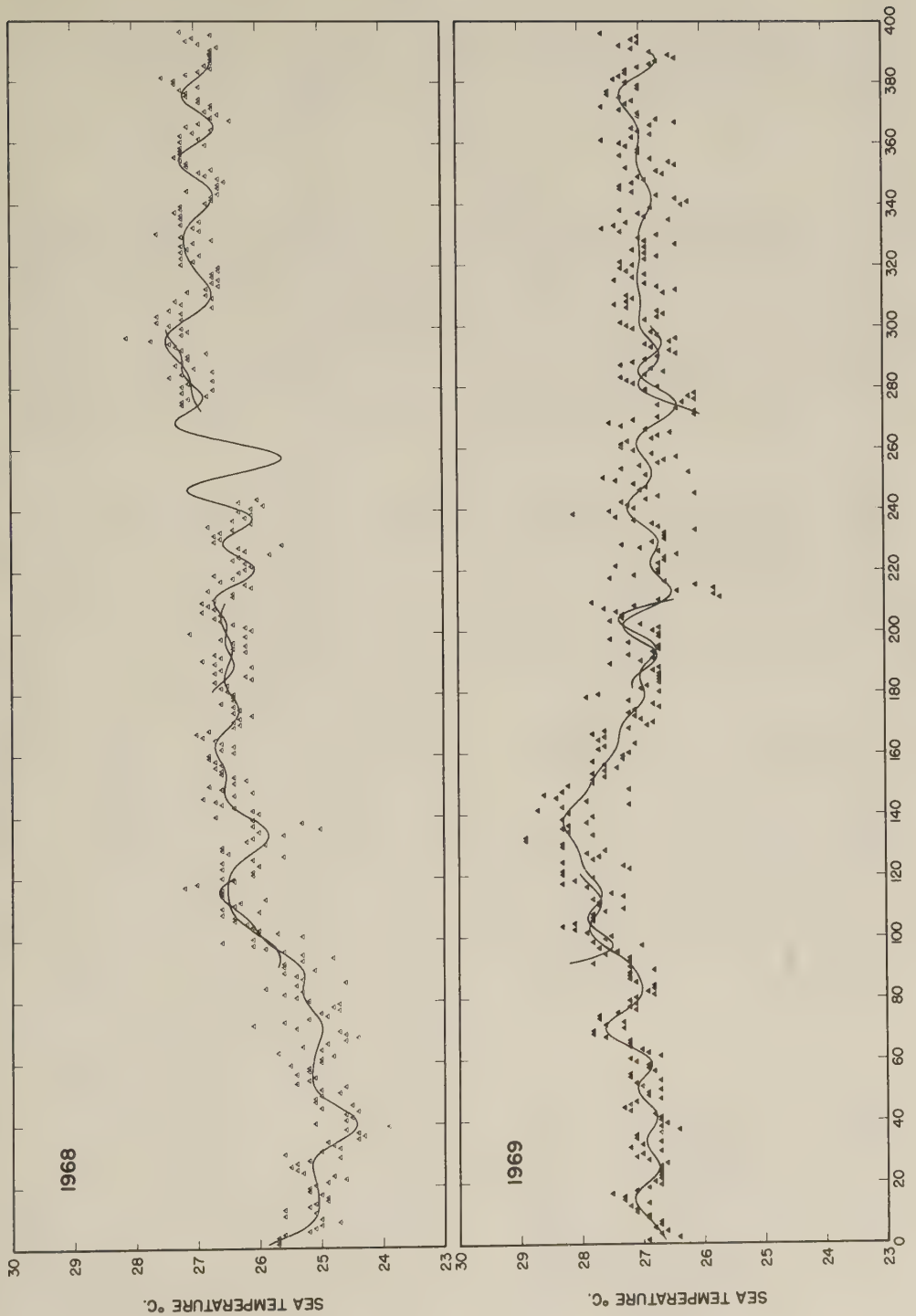
APPENDIX D FIGURE 1.—Sea-surface temperatures, Christmas Island, 1954-69.—*Continued.*



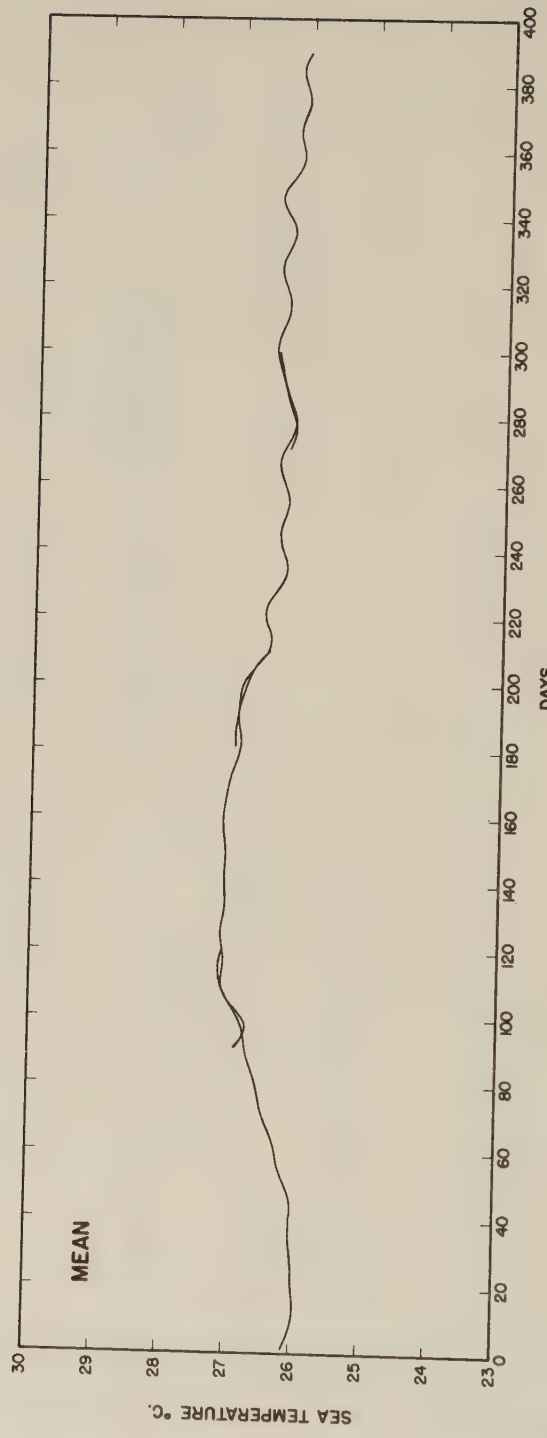
APPENDIX D FIGURE 1.—Sea-surface temperatures, Christmas Island, 1954-69.—*Continued.*



APPENDIX D FIGURE 1.—Sea-surface temperatures, Christmas Island, 1954-69.—*Continued.*



APPENDIX D FIGURE 1.—Sea-surface temperatures, Christmas Island, 1954-69.—*Continued.*



APPENDIX D FIGURE 1.—Sea-surface temperatures, Christmas Island, 1954-69.—*Continued.*

MASKING UNDESIRABLE FLAVORS IN FISH OILS[1]

GISELA JELLINEK[2] AND MAURICE E. STANSBY[3]

ABSTRACT

The odor of fish oil used medicinally may require masking by flavoring materials. During a search for suitable masking materials, fresh, specially refined menhaden oil having a minimum of flavor was stored with and without added flavoring materials for 5 days at 75° F and for longer periods at several lower temperatures. In initial preliminary screening tests with 66 different flavoring materials, the masking of rancid or other unpalatable flavors developing in the stored oil was evaluated by a small panel. In later tests, a large consumer-type panel consisting of untrained laboratory personnel was used to determine the preference for the flavors of those materials that worked best in the screening test and that were of a type approved by the U.S. Food and Drug Administration for use in foods. Several flavoring materials showed promise, particularly those having the flavor of root beer, lemon, wintergreen (methyl salicylate), and wild cherry.

When fish oil is used medicinally—for example, as a cholesterol depressant or as a source of vitamins—the presence of "fishy," rancid, or other flavor components may make it unpalatable. One way of overcoming this problem is to add some flavoring material that will mask the undesirable flavor. It is important that the added flavor be one that is pleasing to most consumers so that we do not merely substitute one undesirable flavor for a slightly more undesirable one. The aim of this work therefore was to find flavoring materials, approved for food use, that would adequately mask the unpleasant flavor components developing in stored menhaden oil (the fish oil produced in largest quantity in the United States) and that would also have a flavor pleasing to most customers.

We carried out this study in two experiments. In Experiment 1, reasonably palatable menhaden oil refined by a special technique was stored for 5 days at room temperature with and without added flavoring materials. A small trained panel was used to determine the efficiency of over 66 different flavoring materials in masking the developing undesirable flavor components in the stored oil. Then, in Experiment 2, those materials giving the best masking action, excluding any not approved for use with food, were further tested by a larger consumer-type panel for hedonic rating of the different flavors resulting from adding the selected flavoring materials to the oil before it was stored.

EXPERIMENT 1—MASKING TESTS

The first series of tests were set up as a rapid screening of many flavoring materials to see which ones best masked the undesirable off flavors that develop in stored menhaden oil. At this stage, no consideration was given to individual preference for the flavor additive, which was investigated in Experiment 2.

MATERIALS

Menhaden oil was specially refined by a combination of clay bleaching, molecular distillation, and treatment with massive quantities of silica gel (Stansby and Jellinek, 1965). This treatment yielded an oil that was free of fishy and rancid flavor components but that still retained some small burnt flavor.

Sixty-six flavor additives that were screened initially included synthetics and isolates,

[1] This research was carried out as a cooperative program between the University of California Food Science and Technology Department, Davis, Calif. 95616, and the Bureau of Commercial Fisheries (now National Marine Fisheries Service) Technological Laboratory, Seattle, Wash. 98102.

[2] Mozartstrasse 15, 69 Heidelberg, Germany.

[3] National Marine Fisheries Service Pioneer Research Laboratory, Seattle, Wash. 98102.

Manuscript received August 1970.
FISHERY BULLETIN: VOL. 69, NO. 1, 1971.

undiluted and in alcoholic solution, essential oils, and imitation flavoring compositions. The additives were obtained from many sources.

METHODS

In the initial work, 5-ml samples of menhaden oil, with or without flavor additive, were held in covered plastic petri dishes (100 by 15 mm) for 5 days at 75° F (22° C). Preliminary tests indicated that 1 part by volume of flavoring material per 400 parts by volume of oil gave about the proper concentration with most flavor preparations, so this concentration was used throughout the work. With the large surface of oil exposed to air in this test, a fairly advanced stage of rancidity was reached in 5 days.

In some of the later work in which larger samples were required, oil in both 200-ml (8-oz) and 25-ml (1-oz) stoppered bottles was stored: (1) at 40° F (4° C) for 8 to 12 weeks, (2) at —20° F (—29° C) for 8 to 12 weeks, and (3) at room temperature—that is, at 75° F (22° C) for 4 weeks.

For various aspects of this work, especially in preliminary observations, paired comparison tests, duo-trio tests, ranking tests and descriptive tests—all described by Jellinek (1964) were used. For most of this work, however, descriptive tests and ranking tests were used; only the descriptive and ranking tests will be tabulated in this report.

Samples of oil were tasted by immersing the tip end of a plastic spoon into the oil and placing the spoon into the mouth. This procedure avoided coating the lips with oil, and it eliminated much of the objection of some panel members to an undesirable oily feel during protracted examination of many samples.

The panel used in this part of the work consisted of 5 to 7 laboratory workers all of whom had had some previous experience with odors and flavors of fish oils. Several preliminary training sessions were held in order for them to become familiar with and be able to use consistent terminology for the odors and flavors to be encountered in the experimental work.

RESULTS

Initial Screening Test

In an initial screening test of all 66 flavoring compounds, a degree-of-masking scale was used as follows: ++, very good masking; +, good masking; ±, good masking when first tasted but did not mask aftertaste; ?, questionable masking; —, negative masking—that is, the taste was not masked (Table 1). The flavoring materials are listed in alphabetical order within each category.

Main-Examination Test

We then made a more detailed examination, paying greater attention to the type of flavor which sometimes varied at different stages during the storage of the oil. The following comments show certain limitations of many of the flavor additives.

Flavoring materials with "green" or "floral" flavor properties.—Because fresh fish oil has a "green-grassy" or "green-cucumber" odor and flavor, two green standards had been worked out in earlier experiments (Stansby and Jellinek, 1965). These standards were cis-hexen-3-ol-1 and Green Aroma Hr (coded sample of Haarmann and Reimer, Holzminden, West Germany,[1] probably: nona-2-enal or nona-2-dienal or a mixture of both (Forss, Dunstone, Ramshaw, and Stark, 1962). These two green standards were tried as masking agents.

Cis-hexen-3-ol-1 contributed a definite green-grassy note to the menhaden oil and also showed very good masking abilities in the exposed menhaden oil.

Green Aroma HR contributed a green-cucumber note to the fish oil but seemed to have prooxidant qualities. In comparison with the control sample, the menhaden oil got rancid faster and reached a higher intensity. These observations seem to be similar to those made about 20 years ago on butter with a high content of di-

[1] The use of trade names is merely to facilitate descriptions; no endorsement is implied.

TABLE 1.—Effectiveness of 66 flavoring materials in masking the fishy flavor and odor of menhaden oil.

Category and substance	Flavor type and descriptions	Masking effect
Synthetics and isolates		
Acetoin	butterlike	±
Agrumen aldehyde	fruity-citrus	−
Anethol, U.S. Pharmacopoeia (U.S.P.)	spicy-anise	++
Benzaldehyde	sweet-bitter almond	−
i-Butyl quinoline	green-spinachlike or earthy (asparagus)	−
Carvol	spicy-caraway	−
Cinnamic aldehyde	spicy-cinnamon	?
Citral	fruity-lemon	±
Ethyl phenyl acetate	sweet-honeylike	+
Ethyl salicylate	wintergreen	++
Eucalyptol	cooling	−
Eugenol	spicy-cloves	−
Foretine	green-mushroomy/earthy	−
Geraniol	green-leafy & floral-rosy	−
Geranyl acetate	green-leafy & floral-rosy	−
Geranyl butyrate	green-leafy & floral-rosy	−
Geranyl propionate	green-leafy & floral-rosy	−
cis-hexen-3-ol-1	green-grassy	++
i-Jasmone	green-leafy	−
Linalool	floral	−
Melonal (2,6-dimethyl-5-hepten-1-al)	fruity-melony	+
Menthol	cooling	−
Methyl nonyl ketone	green-?	−
Methyl salicylate	wintergreen	++
Styralyl acetate	green	−
-Undecalacton	fruity-peach	−
Vanillin	sweet-vanilla	?
Essential oils		
Anise oil, U.S.P.	spicy-anise	++
Bay oil	spicy-bay	−
Caraway oil	spicy-caraway	−
Cassia oil	spicy-cassia	++
Cinnamon oil, U.S.P.	spicy-cinnamon	++
Clove oil	spicy-clove	−
Ginger oil	spicy-ginger	−
Essential oils-Con.		
Lemon oil, U.S.P.	fruity-lemon	+
Lime oil	fruity-lime	+
Orange oil, U.S.P.	fruity-orange	+
Peppermint oil	cooling-peppermint	−
Root beer oil	wintergreen group	++
Spearmint oil, rectified	cooling-spearmint	−
Imitation flavoring compositions		
Blood Orange Flavor	fruity-orange	+
Imitation Boysenberry Flavor	fruity-boysenberry	−
Butter Aroma	butterlike	±
Cherry Bouquet	fruity-cherry or sweet cherry	++
Imitation Cranberry Flavor	fruity-cranberry	−
Fruity Bouquet	fruity	++
Green Aroma HR	green-cucumber	+
Imitation Honey Flavor	sweet-honeylike	+
Imitation Lemon Juice Flavor #51.124A	fruity-lemon	+
Lemon Mint Flavor	fruity-lemon	+
Lime Mint Flavor	fruity-lime	+
Imitation Melon Base	fruity-melon	±
Orange Mint Flavor	fruity-orange	+
Tetrarome Orange	fruity-citrus	+
Violet Flavor	floral-violet	−
Imitation Essence Arrack	fruity-brandy	−
Imitation Butterscotch	sweet-caramel	?
Oil Brandy Flavor	brandy-like	−
Imitation Essence Caramel	sweet-caramel-vanilla	?
Imitation Oil Soluble Flavor Wild Cherry #12009	fruity-cherry	++
Imitation Oil Chocolate	sweet-caramel-chocolate	?
Imitation Essence Cocoa	sweet-malt-chocolate	?
Malt True Concentrate	sweet-malt	−
Imitation Aroma Maple	sweet-maple	−
Imitation Oil Rum, Jamaica #017	fruity-rumlike	++
Tutti Frutti Oil	fruity-candy	++

acetyl. Butter with a high diacetyl content has more butter flavor and turns rancid faster than does butter with a low diacetyl content. For this reason, export butter has to be washed carefully to lower the content of diacetyl (Moncrieff, 1951).

In addition to these two green standards, some other chemicals with green character or floral character, or both, were tried but without success. They are listed among the synthetics and isolates above. Some of them—namely, i-butyl quinoline, foretine, i-jasmone, methyl nonyl ketone, and styralyl acetate—contributed sharpness and a biting note to the menhaden oil.

Geraniol, geranyl acetate, geranyl butyrate, and geranyl propionate contributed a green, somewhat leafy note combined with sharpness. In addition, a flowery "rosy" note was observed. These materials have been recommended repeatedly by aroma companies. However, the materials do not seem to be suitable for use with menhaden oil. The same observation was made with "violet" flavor.

Flavoring materials with "fruity" flavor properties.—Citral added a refreshing lemon odor and flavor to fish oil; but in addition, it is sharp in taste with the sharpness lingering in the aftertaste. Repeat tests with other concentrations confirmed that citral alone is too sharp. In combination with fruity flavoring compositions, it might help to introduce a refreshing note.

Melonal (2,6-dimethyl-5-hepten-1-al) contributed a fruity refreshing note, lingering in the aftertaste. In addition, it gave a greenness similar to that described by some panel members as "green-melony." Unfortunately, the sample turned rancid rapidly toward the end of the

5-day period of storage when melonal was added.

γ-Undecalactone (peach lactone), when used alone, is too artificial in odor and too sharp in flavor.

Lemon oil made the odor of the menhaden oil aromatic-fruity. It was retested with good results.

Lime oil gave a refreshing citrus taste to the menhaden oil, contributed some astringency, but it did not linger in the aftertaste. The aftertaste was more lemon-"candy"-like. (It was probably not pure lime oil; artificial flavoring material probably had been added, giving this "candy"-like flavor.)

Orange oil has good masking properties.

Blood Orange Flavor, Lemon Juice Flavor, Lemon Mint Flavor, Lime Mint Flavor, Orange Mint Flavor, Tetrarome Orange had good masking properties.

Imitation Boysenberry Flavor and Imitation Cranberry Flavor had masking properties for the odor rather than for the flavor. In addition, the flavor was quite artificial and unpleasant. The fruits that were imitated were not recognizable as such either in odor or in flavor. We tried to obtain a natural cranberry oil, but it is not available on the market.

Cherry Bouquet was outstanding in the masking properties of rancidity and oily feeling.

Wild Cherry Flavor also had very good masking properties.

Fruity Bouquet had very good masking properties; the flavor was fruity-candylike.

Imitation Melon Base, in alcoholic dilutions, gave a fruity-melon type of odor. In undiluted form, it smelled fruity and honey sweet. The oily feeling was well masked in the flavor with fruitiness and sweetness lingering in the aftertaste. After the oil was exposed for 1 day, there was in addition some lingering sharpness.

Imitation Oil Rum had good masking properties.

Flavoring materials with "butterlike" flavor properties.—Acetoin contributed a butterlike flavor and feeling, lingered in the aftertaste. The butter feeling is perceivable longer in the aftertaste than is the oily feeling. Unfortunately, the sample became rancid after only 3 days, indicating some prooxidant effect.

Butter Aroma showed good masking properties but only at the start of the test.

Flavoring materials with "sweet" flavor properties.—Benzaldehyde (bitter almond flavor) alone is not satisfactory. It has to be used in a flavoring complex such as Cherry Bouquet.

Ethyl phenyl acetate and Imitation Honey Flavor mask the oily feeling. In addition they contribute a honey flavor.

Vanillin was tried in different concentrations, but the results obtained were not satisfactory.

Flavoring materials with "spicy" flavor properties.—Anethol contributeed an anise flavor. It masked the oily feeling very well and changed it into a pleasant anise flavor (similar to that of cough drops flavored with anise oil or anethol).

Carvol and eugenol were not suitable. They added a sharp, somewhat burnt note to the menhaden oil.

Anise oil showed very good masking properties.

Bay oil, caraway oil, clove oil, and ginger oil were not suitable. They added a sharp, somewhat burnt note to the fish oil.

Cassia oil and cinammon oil were equally suitable.

Flavoring materials of the "wintergreen" group.—Ethyl salicylate, methyl salicylate, and root beer oil all masked the oily feeling very well.

Flavoring materials with "cooling" flavor properties.—Menthol, peppermint oil, and spearmint oil contributed initially only a bland taste and pleasant oily feeling to the menhaden oil. Samples with eucalyptol had a sharp note in flavor. All samples had a rancid flavor at the end of the 5-day storage test at room temperature.

Reduction in the List of Potential Masking Materials

The number of potential flavoring materials for masking the objectionable flavor components in the menhaden oil, based upon the preliminary screening tests, was too large to subject them all to a large-scale consumer-type test and therefore had to be decreased. The most promising flavoring materials for masking were:

Synthetics and isolates:
- Anethol
- Ethyl phenyl acetate
- Ethyl salicylate
- cis-hexen-3-ol-1
- Methyl salicylate

Essential oils:
- Anise oil, U.S.P.
- Cassia oil
- Cinnamon oil, U.S.P.
- Lemon oil
- Orange oil, U.S.P.
- Root beer oil

Imitation flavoring compositions:
- Blood Orange Flavor
- Butter Aroma
- Cherry Bouquet
- Fruity Bouquet
- Imitation Honey Flavor
- Imitation Lemon Juice Flavor #51.124A
- Lemon Mint Flavor
- Lime Mint Flavor
- Orange Mint Flavor
- Tetrarome Orange
- Imitation Oil Rum #017
- Imitation Oil Wild Cherry #12009
- Tutti Frutti Oil

Because using more than a dozen flavoring materials in the large-scale consumer tests was not desirable, we considered limiting further the number of flavoring materials for additional study. The results of this phase of the examination permitted us to eliminate additional materials, based upon the following observations.

Ethyl phenyl acetate was described as perfumelike by some consumers and was therefore disliked by them.

Ethyl salicylate was partly liked, partly disliked by different panel members. The scores for methyl salicylate were higher.

Cis-hexen-ol-1 tested in samples stored at 40° F and —20° F for 8 weeks did not result in observable rancidity. The samples still had a green-grassy character. The control sample stored at 40° F was rancid; the control sample stored at —20° F was almost odorless and was faint cucumber green in flavor.

Even though cis-hexen-3-ol-1 masked the oily feeling and rancidity, it was not liked by the panel.

Cassia oil and cinnamon oil have much the same flavor; cinnamon oil was therefore arbitrarily selected for further experiments.

To reduce the number of fruity flavors, we made a preliminary consumer test. From six flavors—Blood Orange, Lemon Juice, Lemon Mint, Lime Mint, Orange Mint, and Tetrarome Orange—Lemon Juice Flavor was chosen for further experiments.

Fruity Bouquet with its candy, fruitlike flavor was disliked by some panel members who described it as being perfumelike.

Cherry Bouquet not only was outstanding in the masking properties of rancidity and oily feeling but received the highest rating in the consumer test.

Only flavoring materials allowed by the U.S. Food and Drug Administration could be considered. The Cherry Bouquet and Fruity Bouquet are perfume compositions and are not permitted as food additives.

Butter Aroma was not satisfactory. As was already experienced with acetoin, samples flavored with a butter-aroma composition turned rancid faster in the storage test at 40° F than did the control. The 40° F sample was definitely rancid after 8 weeks of storage, although the samples held below freezing were not.

Imitation Honey Flavor was too artificial in flavor and therefore disliked by most of the panel.

Masking of Fish Oil with Pronounced Burnt Flavor

As was described in Materials, menhaden oil was refined both by the regular three-stage (clay bleaching, molecular distillation, silica gel)

process and by a modified two-step process in which the silica-gel procedure was eliminated but in which the collection of distillate during molecular distillation was restricted. Such a procedure greatly simplified refining but resulted in a menhaden-oil product containing considerable burnt-flavor component. Flavoring materials giving best results with the latter oil did not necessarily give optimum results with the silica gel refined oil.

Of the flavoring materials found to be most successful for the ordinarily refined procedure, those with a fruity-type flavor—especially Cherry Bouquet and Fruity Bouquet—masked the burnt flavor better than did such flavors as root beer oil, methyl salicylate, or anethol. None of these compounds was able to mask the burnt flavor completely when added to the freshly distilled oil. After 6 weeks of storage at 40° F (4° C) samples masked with Cherry Bouquet or Fruity Bouquet had no burnt flavor, but considerable remained when root beer oil or methyl salicylate was used, and an intermediate amount remained when anethol was used.

Flavoring materials having good masking properties and giving promise for good consumer acceptability were as follows: anethol, anise oil, cinnamon oil, lemon oil, Lemon Juice Flavor, methyl salicylate, orange oil, root beer oil, Imitation Oil Rum, Imitation Oil Wild Cherry, and Tutti Frutti Oil.

When considerable burnt flavor is present in menhaden oil, such as occurs when the two-stage modified refining process is used, none of the masking agents completely obscures this burnt flavor. Certain fruity flavors such as Cherry Bouquet or Fruity Bouquet are the most effective in masking this flavor, with methyl salicylate or root beer oil being less effective.

EXPERIMENT 2—CONSUMER-TYPE TESTS

The next stage of the investigation was to determine consumer hedonic rating for the several masking substances that had been found to be almost equally suitable for disguising the objectionable flavors developing in menhaden oil during storage.

MATERIALS

The same materials—both menhaden oil and flavor additives—were used in this phase.

The flavors used were those that in Experiment 1 had given the best masking results. Any flavors that were used in Experiment 1 and that were not approved for food additive use by the U.S. Food and Drug Administration were eliminated in this part of the work. Table 2 shows the identity and source of these substances.

TABLE 2.—Flavor components rated in the consumer test.

Flavor material	Suppliers[1]
Anethol, U.S.P.	1,4
Anise oil, U.S.P.	3
Cinnamon oil, U.S.P.	3
Lemon oil, U.S.P.	4
Imitation Lemon Juice Flavor #51.124A	2
Methyl salicylate	1,4
Orange oil, U.S.P.	4
Root beer oil	3
Imitation Oil Rum #017	4
Imitation Oil Wild Cherry #12009	4
Tutti Frutti Oil	4

[1]
1 — Felton Chemicals Co., Inc., Brooklyn, N.Y.
2 — Firmenich, New York, N.Y.
3 — Fiorasynth Laboratories, Inc., New York, N.Y.
4 — Fritzche Brothers, Inc., New York, N.Y.

METHODS

A modified molecular distillation procedure was used. This procedure eliminated the necessity for carrying out the time-consuming treatment with silica gel. The oil was distilled only until the pot residue amounted to 10 % (as contrasted to 3 % in the usual methods). This decreased amount of distillation resulted in much less burnt flavor (although in considerably more burnt flavor than when a silica-gel treatment was used). The oil could be used, however, directly without silica-gel treatment when sufficiently effective masking agents were used.

Oils were stored at (1) 40° F (4° C) (2) at —20° F (—29° C) for 4 to 12 weeks.

The panel for the consumer-type test consisted of Bureau of Commercial Fisheries personnel who had no previous experience in taste testing. The 15 to 20 participants were asked to rate

Name .....

Date .....

Please indicate by check mark (√) how much you like or dislike each sample and rank it in order of preference (1-best, 2-second best, etc.).

Hedonic Scale	Scale	Code	Code	Code
Like very much	1			
Like moderately	2			
Neither like nor dislike	3			
Dislike moderately	4			
Dislike very much	5			

Comments:

Too weak

Satisfactory

Too strong

Flavor recognized as:

Ranking order:

FIGURE 1.—Score sheet for the consumer test.

two to three flavored samples on a hedonic scale, using the score sheet shown in Figure 1.

Five ml of oil was rated by the panel 5 days a week for about 3 months. It was necessary to determine whether a flavor, liked initially, was still liked after continuous intake. Likes and dislikes were expressed on an hedonic scale of 5 points (Fig. 1).

RESULTS

Table 3 summarizes the consumer ratings over the period of test.

Some consumers were consistent in their rating throughout the entire period of the test. Other consumers were consistent only with some flavors but were inconsistent with others.

DISCUSSION

Table 3 shows that all of the tested flavors received high ratings (1 or 2) as main ratings by the consumer-type panel. It should be noted that these high ratings were not given by the consumer panel as a whole but rather by groups within the panel. It also should be noted that there is a split of like and dislike for the same flavor.

This split is understandable, and it may be due to different causes. Individuals with various background show widely different flavor preferences. For example, Europeans who are used to methyl salicylate being used primarily for flavoring medicinal products or in disinfectants would doubtlessly have rated this substance lower for fish-oil masking than did our American panel. In parts of Asia where anise seed

TABLE 3.—Consumer ratings for different flavored fish oil.

Flavoring material added to fish oil	Hedonic ratings[1]				
Anethol	1,	2,		(4)	
Anise oil	(1)	2,		(4)	
Cinnamon oil	1,	2,	(3)	4	
Lemon oil	(1)	2,	(3)	(4)	
Imitation Lemon Juice Flavor #51.124A	1,	2,		(4)	
Methyl salicylate	1,	2,	3,		(5)
Orange oil	(1)	2,	3,	(4)	
Root beer oil	1,	2,	(3)	(4)	
Imitation Oil Rum #017	(1)	2,	(3)	(4)	(5)
Imitation Oil Wild Cherry #12009	1,	(2)	3,	(4)	
Tutti Frutti Oil	1,	2,		(4)	

[1] Rating numbers not in parentheses were the ones given by most consumers; those in parentheses were the ones given by fewer members—for example, lemon oil was liked moderately (Rating 2) by most consumers, but some gave a higher rating (1) and some gave a lower rating (3) or (4).

is grown, frequently anise is disliked as a flavoring material. In addition to differences due to nationality, childhood experience has a definite influence on likes and dislikes. Orange oil is a good example. Panel members who had been forced during childhood to take orange-flavored cod-liver oil as a medicine objected to orange flavor. As can be observed in daily food intake where some persons prefer sweet foods and others prefer acid foods, there is likewise the same split of like and dislike with sweet flavoring materials (cinnamon oil and Tutti Frutti Oil) and with acid flavors (Lemon Juice Flavor).

Even though the consumer-type panel as a whole did not rank the flavors in a definite order of preference, a pronounced like for any of the offered flavors by smaller consumer groups is obvious. This finding should encourage trial of these fish-oil masking flavors with larger consumer groups.

ACKNOWLEDGMENTS

The following concerns supplied information on, and furnished samples of, flavoring materials: Felton Chemicals Co., Inc., Brooklyn, N.Y.; Firmenich, New York, N.Y.; Florasynth Laboratories, Inc., New York, N.Y.; Fritzche Brothers, Inc., New York, N.Y.; Haarmann and Reimer, Holzminden, West Germany; International Flavors and Fragrances, New York, N.Y.; Norda Essential Oil and Chemical Co., New York, N.Y.; Polak's Frutal Works, Middletown, N.Y.; and Ritter and Company, Los Angeles, Calif.

LITERATURE CITED

Forss, D. A., E. A. Dunstone, E. H. Ramshaw, and W. Stark.
1962. The flavor of cucumbers. J. Food Sci. 27(1): 90-93.

Jellinek, Gisela.
1964. Introduction to and critical review of modern methods of sensory analysis (odour, taste, and flavour evaluations) with special emphasis on descriptive sensory analysis (flavour profile method). J. Nutr. Diet. 1(3): 219-260.

Moncrief, R. W.
1951. The chemical senses. 2d ed. Leonard Hill Limited, London. vii + 538 p.

Stansby, Maurice E., and Gisela Jellinek.
1965. Flavor and odor characteristics of fishery products with particular reference to early oxidative changes in menhaden oil. *In* Rudolf Kreuzer (editor), The technology of fish utilization, contributions from research, p. 171-176. Fishing News (Books) Ltd., London.

EARLY DEVELOPMENTAL STAGES OF THE BROWN SHRIMP, *Penaeus aztecus* IVES, REARED IN THE LABORATORY[1]

HARRY L. COOK[2] AND M. ALICE MURPHY[3]

ABSTRACT

The larval and first postlarval stages of the brown shrimp, *Penaeus aztecus* Ives, reared from eggs spawned in the laboratory, as well as the eggs themselves, are described and illustrated. The larvae and first postlarva are compared with those of the pink shrimp, *P. duorarum* Burkenroad, and white shrimp, *P. setiferus* (Linn.).

Commercial shrimp landings from Gulf of Mexico and South Atlantic waters of the United States are comprised mainly of three species: the brown shrimp, *Penaeus aztecus* Ives; the pink shrimp, *P. duorarum* Burkenroad; and the white shrimp, *P. setiferus* (Linn.). The Gulf coast shrimp fishery is the most valuable of domestic commercial fisheries, and in 1968 the value to fishermen for shrimp caught in the Gulf amounted to nearly $95 million. Because of their relative importance, these shrimps are being intensively studied by the National Marine Fisheries Service in an effort to understand more fully their biology and ecology.

Thirteen species of penaeid shrimp representing five genera inhabit the shallow nearshore waters of the northwestern Gulf. At the present time their larvae can only be identified to genus (Cook, 1966). Within genera the larvae are so similar morphologically that at any given stage the various species cannot yet be distinguished. Since adults of the three commercially important species often occur together and overlap in their spawning activity, there is also some intermingling of their planktonic larvae. To answer basic questions about larval distribution, growth, and survival of each species, accurate identification of larvae is essential.

The larval and early postlarval stages of the pink shrimp were described by Dobkin (1961), and those of the white shrimp by Pearson (1939) and Heegaard (1953). These shrimp have five nauplial, three protozoeal, three mysis, and several postlarval stages. Their morphological characteristics during these stages are so alike, however, that biologists still encounter difficulty in differentiating the two species. Since the early developmental stages of the brown shrimp have not been described, the purpose of this paper is to do so and at the same time compare them with corresponding stages of the pink and white shrimps.

METHODS AND MATERIALS

Larvae of the brown shrimp were first successfully cultured in the laboratory during the fall of 1963. Since that time, culture techniques have improved greatly. The methods used in our culture of larval penaeid shrimp were described by Cook and Murphy (1966), Cook (1969), and Cook and Murphy (1969).

Specimens of each stage were preserved for descriptive purposes. Drawings were made with the aid of a camera lucida. The figures of each substage are composite and represent an "average" larvae rather than any one individual. Also, with the exception of the nauplii, appendages on these figures are intended to indicate only relative size and position, not to show details of setation. The enlarged figures of

[1] Contribution No. 309, National Marine Fisheries Service Biological Laboratory, Galveston, Texas 77550.

[2] Formerly National Marine Fisheries Service Biological Laboratory, Galveston, Texas; present address: Division of Contract Research, Texas Division, Dow Chemical Company, Freeport, Texas 77541.

[3] National Marine Fisheries Service Biological Laboratory, Galveston, Texas 77550.

Manuscript received September 1970.
FISHERY BULLETIN: VOL. 69, NO. 1, 1971.

mouth parts and other appendages were taken from two individuals representing each substage. Setules on the setae of the larvae were deliberately omitted, and nauplial appendages were rotated on their axes to avoid cluttering the figures and obscuring important diagnostic characters.

Abbreviations used in the text are: TL = total length, including rostrum when present but excluding caudal spines; W = body width at the point of greatest width; CL = carapace length, including the rostrum; and N = the number of specimens examined.

DESCRIPTION OF DEVELOPMENTAL STAGES

EGG AND HATCHING
(Fig. 1)
Diameter 0.26 mm

Viable eggs are round, golden brown, and translucent. As the nauplius develops, it fills the egg case and can be seen moving sporadically. At hatching, the egg case splits and the posterior portion of the nauplius protrudes. Then the nauplius, unmoving, appears to swell until it is forced from the shell, the entire process taking about 30 sec.

When first hatched, the nauplius rests almost motionless for 3 to 5 min. Although the appendages do not move during this time, spastic movement can be seen within the body near the base of each appendage. Suddenly the nauplius folds its appendages posteriorly along the ventral margins of the body, and, in one quick movement, sheds from its posterior end a loose-fitting exoskeleton and starts swimming actively. At first, the nauplius alternates 2- to 3-sec periods of swimming with resting periods of equal duration.

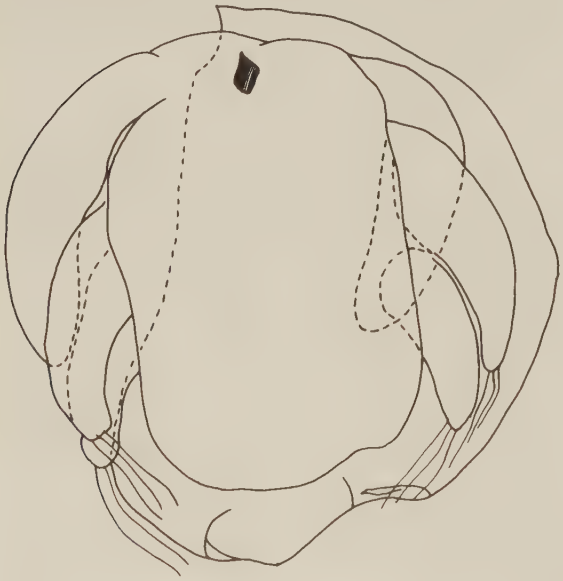


FIGURE 1.—Nauplius emerging from egg.

NAUPLIUS I
(Fig. 2)
Mean TL = 0.35 mm (0.32-0.38 mm)
Mean W = 0.19 mm (0.18-0.21 mm)
N = 55

The pyriform body is unsegmented and possesses a ventrally projecting labrum. An ocellus, which persists in subsequent nauplial substages, is present near the anterior end. The dorsal surface of the body is smooth except for a small median spine posteriorly (Fig. 2b). The posterior portion of the body is rounded and bears a single pair of caudal spines.

The body color in all nauplial substages is a

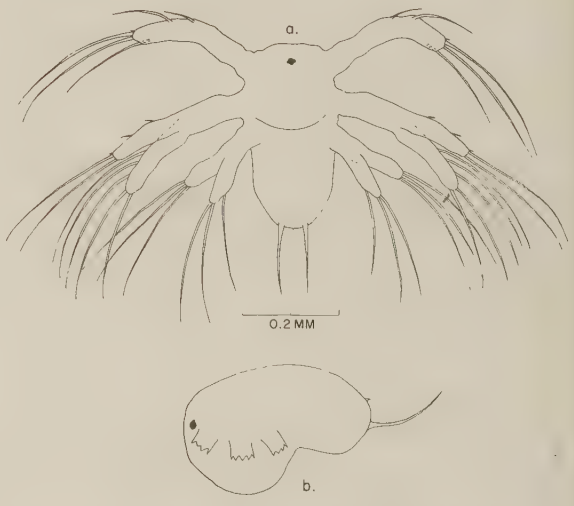


FIGURE 2.—Nauplius I: a, ventral view; b, lateral view.

golden brown, with the appendages tinged red apically. The translucent body appears filled with small granules that flow freely when the cuticle is ruptured.

Three pairs of appendages are present. The first antennae are uniramous and slightly less than three-quarters the length of the body. Each second antenna is biramous, its endopod slightly shorter than the exopod, and approximately three-quarters the body length. The mandibles are biramous and slightly less than one-half the body length.

In this substage all setae are smooth, but in subsequent substages, the longer ones are plumose.

Setation of appendages:

First antenna: Two short ventrolateral; two long terminal plus a small spike; one long dorsolateral.

Second antenna:

Endopod: Two short ventrolateral; two long terminal plus a small spike.

Exopod: Three long ventrolateral; two long terminal.

Mandible: Both branches bear three long setae.

NAUPLIUS II

(Fig. 3)

Mean TL = 0.39 mm (0.36-0.41 mm)
Mean W = 0.20 mm (0.20-0.21 mm)
N = 27

Body shape is similar to that of the first nauplius except that the posterior end is no longer rounded; the portion between the single pair of furcal spines has become straightened. The small dorsomedian spine near the posterior end (present in the first substage) is absent in this substage.

Setation of appendages:

First antenna: One short and one medium ventrolateral; one short, one medium, and one long terminal; one medium dorsolateral.

FIGURE 3.—Nauplius II, ventral view.

Second antenna:

Endopod: Two short ventrolateral; one small spike and two long terminal.

Exopod: Three long ventrolateral; two long and one short terminal.

Mandible: Same as Nauplius I.

NAUPLIUS III

(Fig. 4)

Mean TL = 0.40 mm (0.36-0.43 mm)
Mean W = 0.21 mm (0.20-0.23 mm)
N = 51

The posterior portion of the body is more elongate than in previous substages, but the shape remains essentially the same. The body is slightly depressed between the two developing furcal processes, each of which bears four spines. The small dorsomedian spine, absent in the second nauplius, reappears. The beginnings of ventral appendages can be seen as small indentations posterior to the labrum. The bases of the mandibles have become slightly swollen, and small frontal organs are present at the anterior end of the body.

Setation of appendages:

First antenna: One short and two medium ventrolateral; one short, one medium, and one

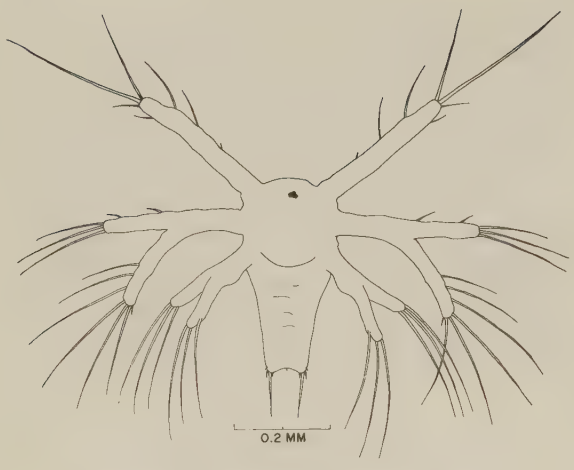


FIGURE 4.—Nauplius III, ventral view.

long terminal; one short dorsolateral.

Second antenna:

Endopod: Two short ventrolateral; three long terminal.

Exopod: Three long ventrolateral; three long and one short terminal.

Mandible: Same as Nauplius I.

NAUPLIUS IV

(Fig. 5)

Mean TL = 0.44 mm (0.41-0.47 mm)
Mean W = 0.21 mm (0.20-0.22 mm)
N = 35

The posterior portion of the body has become more slender and two definite rounded furcal processes are formed, each one with six spines. The small dorsomedian spine on the body is absent and does not reappear in later substages. Ventral appendages (first and second maxillae and first and second maxillipeds), still covered by the cuticle, are visible posterior to the mandibles. Frontal organs are present.

Setation of appendages:

First antenna: Same as Nauplius III.

Second antenna:

Endopod: Two short ventrolateral; one short and three long terminal.

Exopod: Four long ventrolateral; two long, one medium, and one short terminal.

Mandible: Same as Nauplius I.

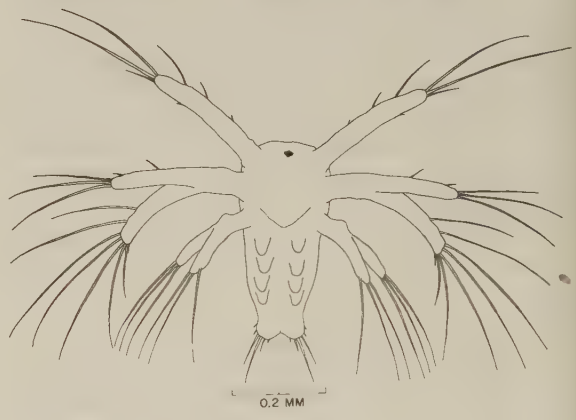


FIGURE 5.—Nauplius IV, ventral view.

NAUPLIUS V

(Fig. 6)

Mean TL = 0.50 mm (0.43-0.58 mm)
Mean W = 0.20 mm (0.18-0.22 mm)
N = 41

The body is further elongated and the furcal processes are more pronounced, each giving rise to seven spines. The maxillae and maxillipeds are now external and show more advanced development. The swelling at the base of the mandible is large and prominent and has a masticatory surface composed of several rows of small teeth. The endopod and the exopod of the mandible are frequently hollow and transparent. The outline of a developing carapace can be seen on the dorsal surface of the body, and frontal organs are present.

In living specimens, eyes and an anal canal are visible internally. In preserved specimens, the anal canal appears to open externally.

It was not possible to determine if the appendages were truly segmented. The appendages of some specimens appeared segmented, i.e., their surfaces possessed annular indentations; those of others did not.

FIGURE 6.—Nauplius V, ventral view.

Setation of appendages:

First antenna: Two short and one medium ventrolateral; two long and one medium terminal; two medium and one short dorsolateral.

Second antenna:

Endopod: Two short and one medium ventrolateral; one medium and three long terminal.

Exopod: Five long ventrolateral; three long and one short terminal.

Mandible: Same as Nauplius I.

PROTOZOEA I

(Fig. 7)

Mean TL = 0.96 mm (0.89-1.21 mm)
Mean CL = 0.45 mm (0.40-0.49 mm)
N = 40

With the molt from Nauplius V to Protozoea I, the larvae change radically. A large, loose-fitting carapace covers the anterior portion of the body. The narrow posterior portion is divided into a six-segmented thorax and an unsegmented abdomen. The masticatory surface of the mandible has become greatly enlarged, and the endopod and exopod have been lost. The maxillae and maxillipeds are large and functional.

The carapace is rounded with a median notch at the anterior end; two rounded frontal organs are the only protuberances on it. An ocellus, which persists in subsequent protozoeal substages, is present between a pair of compound eyes covered by the carapace. The labrum is smaller than in the preceding stage and has a short spine on its anterior margin. Two lobes of the labium, with short bristles on their inner margins, are posterior to the labrum. The mandibles curve inward and several of their teeth can be seen between the labrum and labium.

The first antenna, which is about equal in length to the endopod plus the protopod of the second antenna, is composed of three major segments. The basal segment is divided into five subsegments and bears one short seta. The second segment possesses three setae, two ventrolateral, and one posterolateral. The distal segment has three terminal and three subterminal setae.

The second antenna consists of a protopod of three segments, an endopod of two segments, and an exopod of 10 segments. The endopod bears one seta at the juncture with the protopod, another on the first segment, two at the juncture of the first and second segments, and five terminal setae on the distal segment. The exopod has eight setae on its ventrolateral and two on its dorsolateral margins, as well as three terminal setae.

The mandible has lost its exopod and endopod. The masticatory surface now faces medially and has several rings of teeth.

The first maxilla is composed of an unsegmented protopod, an endopod of three segments, and a small knoblike exopod. The protopod consists of two large lobes, each bearing several stout, toothed spines. The first segment of the endopod possesses two or three setae; the second, two; and the distal, five. The exopod bears four setae.

The second maxilla is about the same size as the first. It has an unsegmented protopod, an endopod of four segments, and a knoblike exopod. The protopod has five lobes on its ventral margin; the basal lobe bears approximately eight setae, the remainder three to six. The first three segments of the endopod each

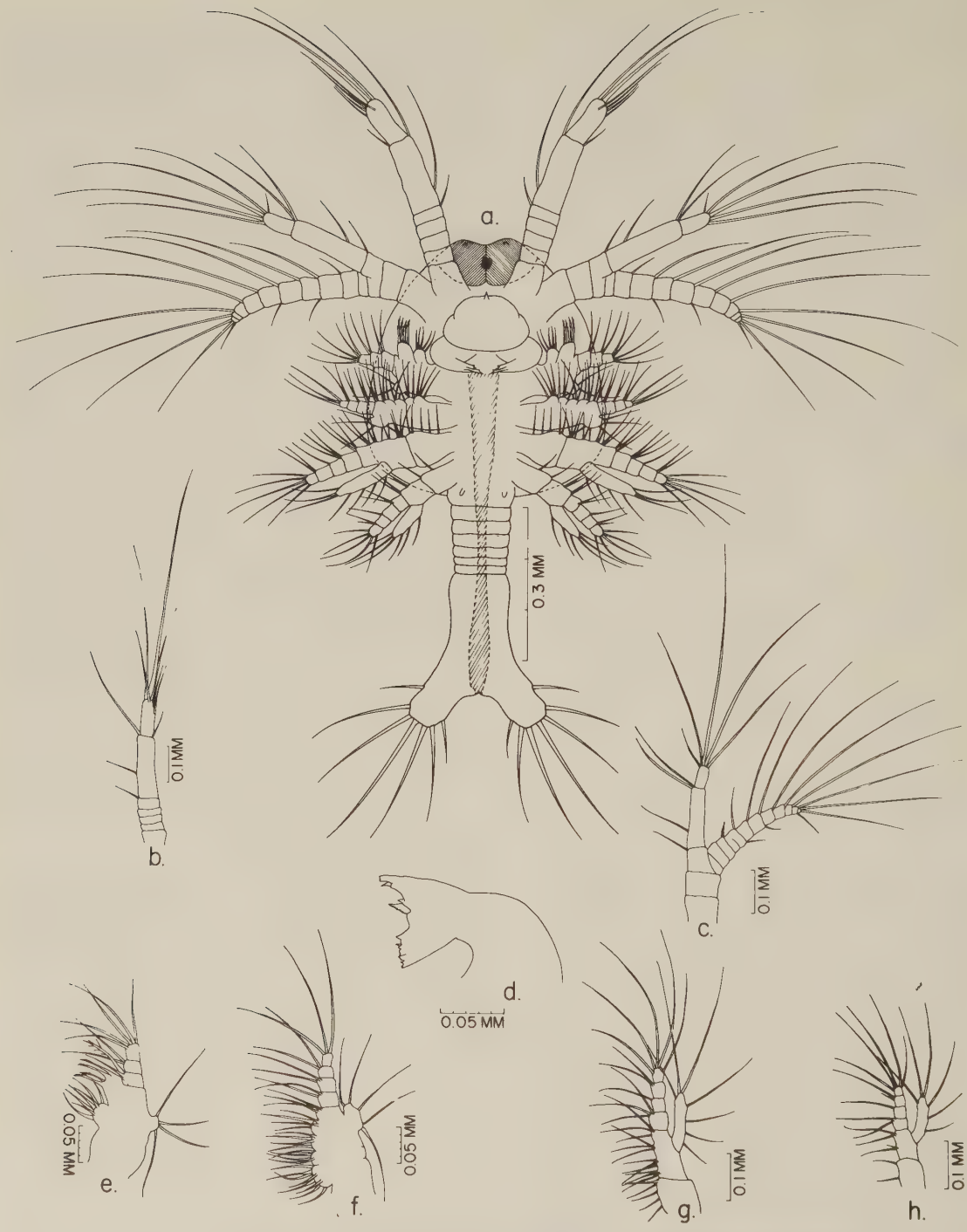


FIGURE 7.—Protozoea I: a, ventral view; b, antenna I; c, antenna II; d, mandible; e, maxilla I; f, maxilla II; g, maxilliped I; h, maxilliped II.

have two setae, and the fourth, three. The exopod has five setae.

The first maxilliped is biramous and longer than the maxillae. It has a protopod of two segments, an endopod of four segments, and an unsegmented exopod. The protopod bears about 17 setae. The basal segment of the endopod possesses three setae; the second, one or two; the third, two; and the terminal, five. The exopod has four lateral and three terminal setae.

The second maxilliped, though smaller, is almost identical to the first. The protopod bears six setae. The endopod is composed of four segments, the first and third giving rise to two setae; the second, one or two; the fourth, five. The exopod has three lateral and three terminal setae.

The third maxilliped is present only as a small bud.

The caudal furcae each retain seven spines and are separated by a well-defined anal opening. The digestive tract is visible posterior to the labrum.

The body is colorless and almost transparent with the exception of two red spots, one on each side of the anal opening.

PROTOZOEA II

(Fig. 8)

Mean TL = 1.71 mm (1.28-2.01 mm)
Mean CL = 0.80 mm (0.72-0.87 mm)
N = 25

The most apparent modification from the preceding substage is the presence of stalked compound eyes. Additional features that characterize this substage are a ventrally projecting rostrum, a pair of bifurcate supraorbital spines, and a segmented abdomen.

Frontal organs are absent in this and later stages.

Segmentation of the appendages remains the same as described for the first protozoea. The only changes in setation are on the first antenna. Several setules are added near the posterolateral seta on the second segment, and an additional terminal seta is found on the last segment. Rudiments of the third maxilliped and five pairs of pereiopods are present.

The abdomen is divided into six segments, the telson not being separated from the sixth. The number of furcal spines remains constant at seven pairs.

PROTOZOEA III

(Fig. 9)

Mean TL = 2.59 mm (2.40-2.59 mm)
Mean CL = 1.06 mm (0.93-1.40 mm)
N = 15

The principal differences between this substage and the preceding one are the presence of biramous uropods and spines on the abdominal segments.

The carapace is close fitting and covers all but the last three thoracic somites. The supraorbital spines are no longer bifurcate.

The five subsegments comprising the basal section of the first antenna in the preceding protozoeal substages have fused into a single unit. The ventrolateral seta that originated from the middle of the second segment has been lost, and a similar one is present on the distal margin. The second antenna, mandible, and maxillae remain essentially the same as in the preceding substage. Two setae have been added to the exopod of the first maxilliped. The first segment of the endopod and the exopod of the second maxilliped have gained a seta. Although the third maxilliped and five pereiopods have developed further and are now biramous, they remain functionless.

The abdomen is divided into six segments, the telson being distinct from the sixth segment. The sixth segment is about three-fourths the length of the preceding five combined. Each of the first five segments has a dorsomedian spine on its posterior margin. The fifth segment also possesses a pair of midlateral spines, and the sixth somite has paired midlateral and ventrolateral spines.

A pair of biramous uropods are present, originating from the ventroanterior margin of the telson. The exopod, slightly longer than the endopod, bears five or six setae at its apex.

An additional pair of caudal spines have been added medially on the telson, making a total of eight pairs.

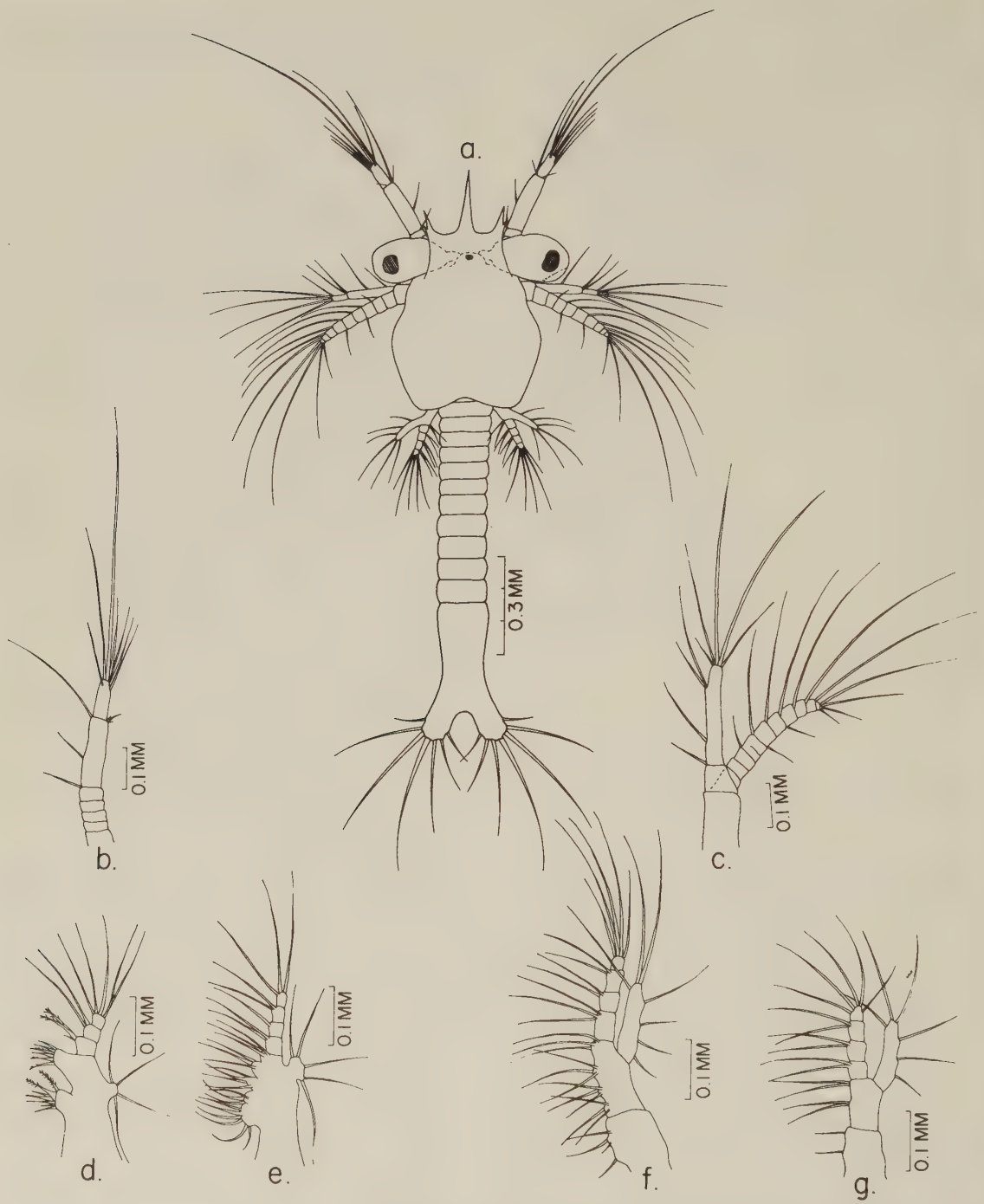


FIGURE 8.—Protozoea II: a, dorsal view; b, antenna I; c, antenna II; d, maxilla I; e, maxilla II; f, maxilliped I; g, maxilliped II.

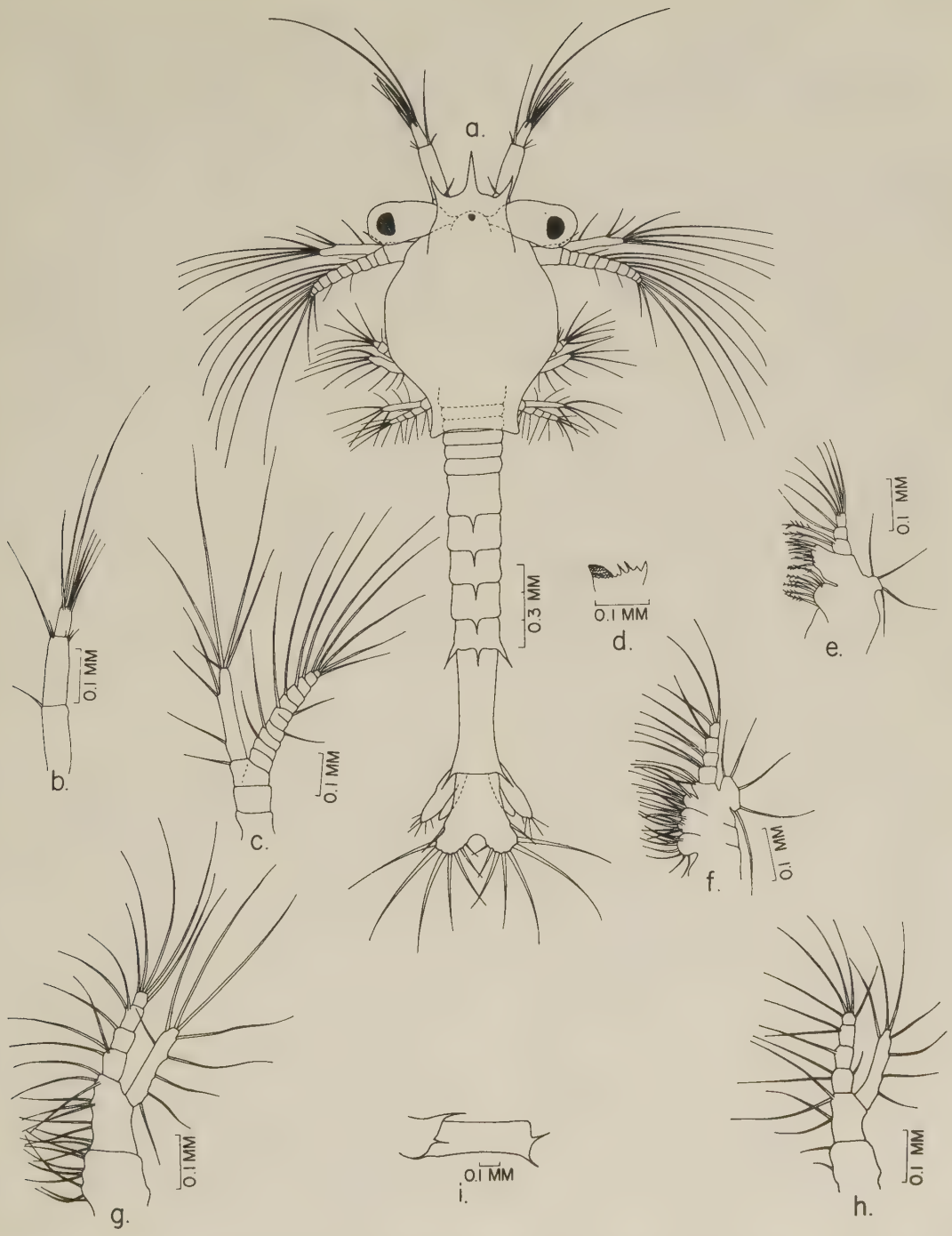


FIGURE 9.—Protozoea III: a, dorsal view; b, antenna I; c, antenna II; d, teeth of mandible; e, maxilla I; f, maxilla II; g, maxilliped I; h, maxilliped II; i, abdominal segments V and VI.

MYSIS I
(Fig. 10)
Mean TL = 3.3 mm (3.2-3.5 mm)
Mean CL = 1.2 mm (1.1-1.3 mm)
N = 18

With the molt from the third protozoeal to the first mysis substage, the larvae undergo another radical change and assume a more shrimplike appearance. The most apparent change is the development of functional pereiopods with long brushlike exopods. The antennae also undergo considerable change, with the exopods of the second antennae becoming modified to form flattened antennal blades.

The carapace fits the body more closely than in preceding stages and covers all but the last two thoracic somites. The rostrum is not depressed as in the protozoeal substages, but protrudes forward on a horizontal plane. Supraorbital spines are still present although reduced in size. A small spine now occurs on the anteroventral corners of the carapace. In addition, a pair of hepatic spines have been added to the carapace, one spine on each side originating from a point located approximately one-sixth the carapace length from the anterior margin.

An ocellus is present in this and subsequent mysis substages.

The first antenna is composed of three segments, the first being 1½ times the length of the second and third combined. Numerous setae now occur along the appendage, and several arise at the apex of each segment. In addition, a prominent ventromedian spine is present on the first segment. The distal segment gives rise to two unsegmented branches, the external one bearing six or seven setae and being twice as long as the internal one, which bears two terminal setae.

The second antenna consists of a protopod of two segments, an unsegmented endopod with three lateral and three terminal setae, and a flattened, unsegmented, bladelike exopod with a single lateral seta and 11 setae along the medial and terminal margins.

The mandible and maxillae remain essentially the same as in the preceding substage except that the exopod of the second maxillae has become enlarged and bears 10 setae. The first and second segments of the endopod of the first and second maxillipeds have acquired an additional seta. The exopod of the first maxilliped has gained a seta and that of the second has lost three. The third maxilliped has evolved further and is now longer than the first two. It has a two-segmented protopod that bears two setae. The first segment of the five making up the endopod possesses two setae; the second, one; the third, none; the fourth, three; and the fifth, five. The unsegmented exopod has five or six terminal and subterminal setae.

The five pairs of pereiopods have undergone considerable enlargement and their exopods serve as the principal swimming organs during the mysis stage. The endopods of the first three pairs are modified into rudimentary chelae that have four or five terminal setae. The first pereiopod consists of a protopod of two segments, an unsegmented endopod, and an exopod which bears five or six terminal and subterminal setae. The last four pereiopods were not examined in detail.

The dorsomedian spines of the first two abdominal segments have been lost while those on the third, fourth, and fifth segments are still prominent. The fifth segment retains a pair of midlateral spines. A dorsomedian and a ventromedian spine are present on the sixth segment in addition to the paired midlateral and ventrolateral spines found in the preceding substage. Anlages of the pleopods can be seen on the ventral surface of the first five abdominal segments.

The uropod has developed an unsegmented protopod that possesses a large posteroventral spine and a smaller posterolateral spine. The endopod carries 11 setae on its medial and terminal borders, while the exopod, which has about 13 setae on its medial and terminal margins, has, in addition, a prominent spine on its posterolateral edge.

The telson is cleft terminally and bears seven pairs of terminal and one pair of lateral spines.

FIGURE 10.—Mysis I: a, dorsal view; b, lateral view; c, antenna I; d, antenna II; e, mandible; f, maxilla I; g, maxilla II; h, maxilliped I; i, maxilliped II; j, maxilliped III; k, pereiopod I.

MYSIS II
(Fig. 11)
Mean TL = 3.8 mm (3.3-4.2 mm)
Mean CL = 1.3 mm (1.2-1.4 mm)
N = 11

This substage can be distinguished from the first mysis by the presence of unsegmented pleopods and a spine on the antennal blade.

The addition of a dorsal spine on the rostrum is the only change in armature of the carapace which now covers the entire thorax.

The terminal branches of the first antenna are almost equal in length. A developing statocyst appears as a slight bulge near the base of the appendage.

Setation on the endopod of the second antenna has been reduced to a single terminal seta. The number of setae on the exopod has increased to 18, and they occur along the medial border and around the tip to the point of insertion of a subterminal spine on the lateral margin. A spine has been added to the terminus of the protopod.

The mandible has developed a small unsegmented palp.

The exopod of the first maxilla is no longer present; that of the second maxilla has increased in size and now bears 13 setae. A seta now arises from the protopod of the first maxilliped at a point between the insertion of the endopod and exopod. In addition to a seta on the distal segment, the endopod of the second maxilliped gains a fifth segment that does not possess setae. The protopods of the third maxilliped and first pereiopod have gained a seta. A single seta on the basal segment is the only one present on the three segments that have been added to the endopod of the first pereiopod. Rudiments of gills are present as small protuberances on the bases of the protopods of the maxillipeds and first pereiopods.

The armature of the abdomen and uropods is unchanged from the preceding substage. Rudimentary, unjointed pleopods are present on the ventral surface of the first five abdominal segments.

The telson has six pairs of terminal and two pairs of lateral spines.

MYSIS III
(Fig. 12)
Mean TL = 4.3 mm (3.9-4.7 mm)
Mean CL = 1.4 mm (1.3-1.5 mm)
N = 21

In this substage, the pleopods and endopod of the second antenna are composed of two segments. These characters serve to differentiate third mysis from preceding substages.

Spination of the carapace remains essentially the same as in Mysis II, although a second dorsal spine on the rostrum was found in approximately one-half of the preserved specimens.

The outer branch arising from the distal segment of the first antenna is longer than the inner branch and is composed of two segments. A lateral seta has been added to the endopod of the second antenna which is now also composed of two segments; the exopod likewise possesses one more seta.

The mandibular palp is slightly longer and has a weak apical seta.

The first maxilla and first maxilliped remain unchanged. The exopod of the second maxilla has become elongate and has 18 setae, while those of the second and third maxillipeds and first pereiopod have two segments. The fourth segment of the endopod of the second maxilliped has gained one seta, as has the exopod. One seta has been added to the second segment of the endopod of the third maxilliped and two to the third; the fourth has lost one. The endopod of the first pereiopod is composed of five segments, with the fourth forming the propodus of the chela and the fifth the dactylus; the second segment has gained one seta, and the third, two. The gills on the maxillipeds and first pereiopod have enlarged.

The only change of consequence in the posterior portion of the body involves the pleopods, which are now composed of two segments and bear two or three terminal setae.

FIGURE 11.—Mysis II: a, lateral view; b, antenna I; c, antenna II; d, maxilla I; e, maxilla II; f, maxilliped I; g, maxilliped II; h, maxilliped III; i, pereiopod I; j. tip of telson.

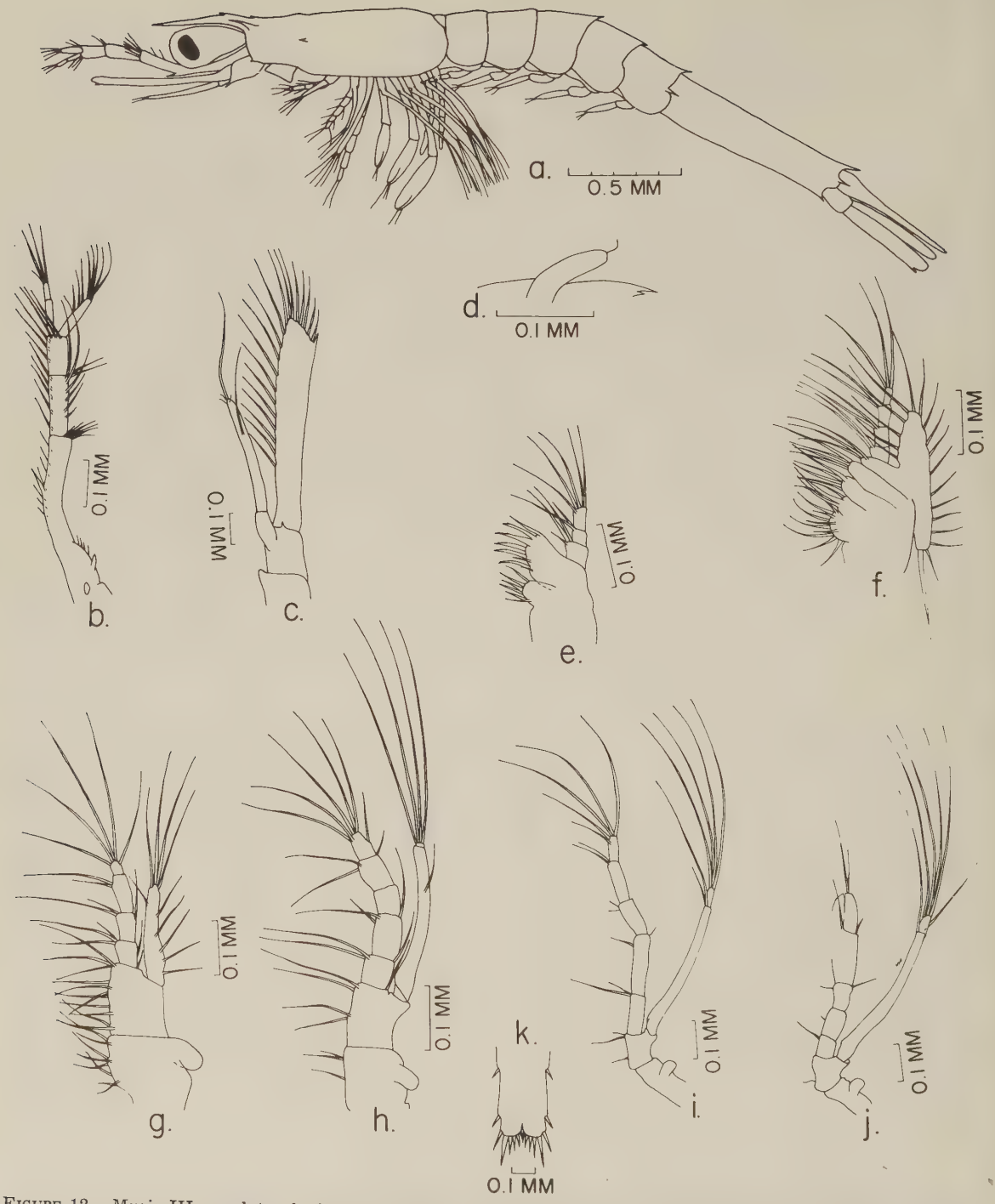


FIGURE 12.—Mysis III: a, lateral view; b, antenna I; c, antenna II; d, mandibular palp; e, maxilla I; f, maxilla II; g, maxilliped I; h, maxilliped II; i, maxilliped III; j, pereiopod I; k, tip of telson.

POSTLARVA I

(Fig. 13)

Mean TL = 4.6 mm (4.2-5.0 mm)
Mean CL = 1.5 mm (1.4-1.6 mm)
N = 15

No drastic changes in morphology are associated with the molt from the third mysis to the first postlarval stage. The pleopods, now well developed and setose, are the principal swimming organs. There is usually a reduction in the size of the exopods of the pereiopods, which, if present, are only vestigial.

The carapace is much the same as in the third mysis. The rostrum bears one or two spines and extends slightly beyond the distal border of the eye. The small spine present on the anteroventral corners of the carapace in the preceding substage is absent. The supraorbital spines are now minute or absent. A pair of hepatic spines and ocelli are present.

The inner branch of the first antenna is composed of two segments, and the outer, three. The statocyst at the base of the first antenna is fully developed. The endopod of the second antenna is composed of five or six frequently indistinct segments. The exopod bears 23 setae.

The mandibular palp is two-segmented and possesses five setae.

The endopods of the first and second maxillae have been reduced greatly and are now unsegmented and usually without setae. Setation of the protopod of the second maxilla has been reduced while its exopod has become enlarged and now bears 21 setae.

The first maxilliped retains only rudiments of its endopod and exopod. The second and third maxillipeds and the first pereiopod have lost all but a vestige of their exopods. The endopod of the second maxilliped has become recurved, and its setation has changed greatly: the first segment has three setae; the second, four; the third, one; the fourth, five; and the fifth, six. The second and third segments of the endopod of the third maxilliped have each gained one seta, the fourth, three; the number of setae on the terminal segment varies from three to six. The dactyl of the first pereiopod now possesses several small teeth and short bristles terminally.

Each pleopod is composed of two segments, the distal one bearing about 10 setae.

The presence of dorsomedian spines on the third, fourth, and fifth abdominal segments is variable. Such spines may be absent or present on one or more of the segments. The midlateral spines have been lost from the fifth and sixth segments. The sixth segment retains a dorsomedian and paired ventrolateral spines.

The telson, which is now only faintly cleft, bears five pairs of terminal and three pairs of lateral spines.

COMPARISON WITH PINK AND WHITE SHRIMP

During the fall of 1964, pink shrimp hatched from eggs spawned in the laboratory were reared to postlarvae. White shrimp were reared during the summer of 1966. Examination of these larvae showed them to be identical to brown shrimp larvae in setation and other major morphological characteristics. Various parts of the body were measured to determine if body proportions differed between the species; the results proved inconclusive.

Dobkin (1961) described the larval development of the pink shrimp but was absolutely certain only of the identity of the nauplial and first protozoeal substages which he obtained from eggs hatched in the laboratory. Descriptions of the more advanced stages were based on specimens sorted from plankton samples. When the pink shrimp we had reared were compared with the specimens described by Dobkin, several differences were noted. These are listed in Table 1.

Pearson (1939) and Heegaard (1953) described the larval development of the white shrimp from material taken in plankton tows. Comparison of these descriptions and our specimens was not attempted because we feel both Pearson's and Heegaard's descriptions of the later stages are not detailed enough for itemized comparison. In addition, Heegaard's editors felt that his figures of the first and second protozoeae were not referable to *P. setiferus*, but should be attributed to *Trachypenaeus, Sicyonia,* or *Xiphopenaeus*. From material at our disposal it

FIGURE 13.—Postlarva I: a, lateral view; b, antenna I; c, antenna II; d, mandibular palp; e, maxilla I; f, maxilla II; g, maxilliped I; h, maxilliped II; i, maxilliped III; j, pereiopod I; k, tip of telson.

TABLE 1.—Comparison between published description of *P. duorarum* and specimens examined by authors

Substage and body part	Dobkin (1961)	Cook and Murphy
Nauplius III		
Antenna I	No mention of posterolateral seta.	A minute posterolateral spine may be present.
Caudal spines	Three pairs.	Three or four pairs.
Nauplius IV		
Antenna I	Two anterolateral and no posterolateral spines.	Two or three anterolateral spines. Minute posterolateral spine may be present.
Caudal spines	Five pairs.	Six pairs.
Nauplius V		
Antenna I	Two posterolateral setae.	Two or three posterolateral spines.
Protozoea I		
Antenna I	Five terminal and subterminal setae. No posterolateral seta on middle segment.	Six terminal and subterminal setae. Middle segment with short posterolateral seta.
Protozoea II and III		
Antenna I	Five terminal and subterminal setae.	Seven terminal and subterminal setae.
Mysis		
Sixth abdominal segment	Two pairs of posterolateral spines.	One pair of posterolateral spines.
Protopod of uropod	Three spines on distal margin.	Two spines on distal margin.

would seem that the editors were correct and that the figures presented are species of *Trachypenaeus*.

LITERATURE CITED

COOK, HARRY L.

1966. A generic key to the protozoean, mysis, and postlarval stages of the littoral Penaeidae of the northwestern Gulf of Mexico. U.S. Fish Wildl. Serv., Fish. Bull. 65(2): 437-447.

1969. A method of rearing penaeid larvae for experimental studies. *In* M. N. Mitakidis (ed.), Proceedings of the world scientific conference on the biology and culture of shrimps and prawns, FAO (Food Agr. Organ. U.N.) Fish. Rep. 57, 3: 709-715.

COOK, HARRY L., AND M. ALICE MURPHY.

1966. Rearing penaeid shrimp from eggs to postlarvae. Proc. 19th Annu. Conf. Southeast. Ass. Game Fish Comm., p. 283-288.

1969. The culture of larval penaeid shrimp. Trans. Amer. Fish. Soc. 98(4): 751-754.

DOBKIN, SHELDON.

1961. Early developmental stages of pink shrimp, *Penaeus duorarum*, from Florida waters. U.S. Fish Wildl. Serv., Fish. Bull. 61: 321-349.

HEEGAARD, POUL E.

1953. Observation on spawning and larval history of the shrimp, *Penaeus setiferus* (L.). Publ. Inst. Mar. Sci., Univ. Tex. 3(1): 73-105.

PEARSON, JOHN C.

1939. The early life histories of some American Penaeidae, chiefly the commercial shrimp, *Penaeus setiferus* (Linn.). Bull. U.S. Bur. Fish. 49(30): 1-73.

PROTEIN AUTOLYSIS RATES AT VARIOUS pH'S AND TEMPERATURES IN HAKE, *Merluccius productus*, AND PACIFIC HERRING, *Clupea harengus pallasi*, AND THEIR EFFECT ON YIELD IN THE PREPARATION OF FISH PROTEIN CONCENTRATE

BARBARA KOURY, JOHN SPINELLI, AND DAVE WIEG[1]

ABSTRACT

The rate of protein autolysis at temperatures ranging from 30° to 80° C and at pH's ranging from 3.0 to 7.0 were determined on hake and Pacific herring. Autolysis rates were generally greatest at acidic pH's and began to decrease after temperatures exceeded 50° C. Autolysis rates were much greater in hake than in Pacific herring. The yield of fish protein concentrate prepared from hake showed a close inverse correlation to the degree of autolysis.

The production of fish protein concentrate (FPC) requires a process that efficiently removes oil and water from the fish and provides high yields of protein. Although FPC can be prepared by several different methods (Knobl, 1967), the most effective procedures developed to date are based on systems in which comminuted fish is successively extracted with a suitable solvent system.

Dambergs (1969), in studying the extracting efficiency of isopropyl alcohol (IPA)-water mixtures in producing FPC from herring, found that low molecular weight compounds were readily removed with these solvent systems. Fish flesh and viscera contain highly active catheptic enzymes which utilize fish tissue as a substrate, forming low molecular weight protein degradation products (Siebert, 1962; Ting, Montgomery, and Anglemeier, 1968). Normal autolysis of fish tissue during storage has been related to decreased yields in FPC production. Dubrow, Brown, Pariser, Miller, Sidwell, and Ambrose (1971) found that when ice-stored fish was used to make FPC, the yield was significantly lower than the yield obtained when FPC was prepared from freshly caught fish. In another study by Dubrow and Hammerle (1969), in which FPC was prepared from samples of comminuted fish held in 91 % IPA for various lengths of time, similar results were obtained.

Preliminary studies in this laboratory, on the development of an aqueous process for FPC production, indicated that under certain conditions significant protein losses may also occur during actual processing procedures as a result of enzymatic hydrolysis.

In solvent extraction procedures for FPC production, the yield of product (excluding physical losses) is dependent upon the amount of proteinaceous material soluble in the extracting solution. While losses can be controlled to some extent by the choice of solvent systems, the possibility of losses due to enzymatic degradation of protein must also be considered.

The purposes of this study were as follows:

1. To determine the effect of pH, time, and temperature on the rate of protein autolysis in two species of fish that are considered for use in the production of FPC.

2. To determine the effect of autolytic activity on FPC yields.

[1] National Marine Fisheries Service Technological Laboratory, 9725 Montlake Boulevard East, Seattle, Wash. 98102.

Manuscript received September 1970.

PROTEOLYTIC ENZYME ACTIVITY IN WHOLE AND EVISCERATED FISH

Presented in this experiment are data on the effect of time, temperature, and pH on the rate of proteolytic enzyme activity in samples of whole and eviscerated comminuted fish.

MATERIALS AND METHODS

Fish

Hake, *Merluccius productus*, and Pacific herring, *Clupea harengus pallasi*, were used in this study. Hake samples were obtained from both coastal waters (outside hake) and Puget Sound (inside hake). Herring were obtained from Bellingham Bay. All samples were obtained fresh and were immediately frozen and held at —20° C.

Preparation of Samples

To insure sample homogeneity, lots of fish were partially thawed and then ground in a Hobart grinder[2] through a 1/8-inch plate. The ground fish was mixed well and divided into portions of approximately 50 g each. These were frozen to —40° C in a plate freezer and stored at —20° C.

Sufficient comminuted fish was prepared to permit running all pH and temperature variables on subsamples from the same lot. Samples of herring and outside hake were prepared from both whole and eviscerated fish. With inside hake, autolytic rates were measured only on whole fish.

METHODS

Fifty grams of comminuted fish were allowed to thaw at room temperature and then were mixed well with 100 ml of H_2O to form a slurry. The pH of the slurry was adjusted to the desired level with 0.1 M HCl and then sufficient water was added to give a final volume of 250 ml. After dilution, the sample was placed in a water bath.

Aliquots of the slurry were taken (1) immediately after the final dilution was made, (2) when the sample reached the desired temperature, and (3) at intervals of 10, 20, 30, and 60 minutes after the sample reached the desired temperature. These aliquots were mixed immediately with an equal volume of 10% TCA, allowed to stand for 30 min, and then filtered. The nonprotein nitrogen (NPN) content of the filtrates was determined by the procedure of Lowry, Rosebrough, Farr, and Randall (1951) and is presented in terms of optical density (OD) measurements at 500 mμ.

Rates of proteolytic enzyme activity at pH 6.0, 5.0, 4.5, 4.0, and 3.0 were measured at temperatures of 30°, 40°, 50°, 60°, 70°, and 80° C. Controls consisted of samples in which no pH adjustment had been made.

RESULTS AND DISCUSSION

The results of the above experiments are shown in Figures 1 through 5.

In whole herring (Fig. 1), no significant degree of proteolytic enzyme activity was observed at pH levels higher than pH 5.0 over the temperature range studied. At pH 4.0-4.5, maximum activity was found at 40° C, and at pH 3.0, maximum activity was found at 30° C.

Under these experimental conditions, only negligible proteolytic enzyme activity was observed in eviscerated herring samples (Fig. 2) indicating that in herring proteolytic enzymes are essentially of visceral origin.

Figures 3 and 4 show the results of the experiments using whole inside and outside hake. At 30° C, the rate of proteolytic activity in both control samples was negligible. As the pH was lowered, the rate of activity increased. At 40° C, the rate increased at all pH levels, and these rates remained elevated until the temperature exceeded 60° C. In these two samples, differences were observed in the pH of optimum activity at various temperatures. These variations were attributed to differences in the age, feeding habits, etc., of the two populations.

The effects of pH and temperature on the rate of enzyme activity in eviscerated outside hake

[2] The use of trade names is merely to facilitate descriptions; no endorsement is implied.

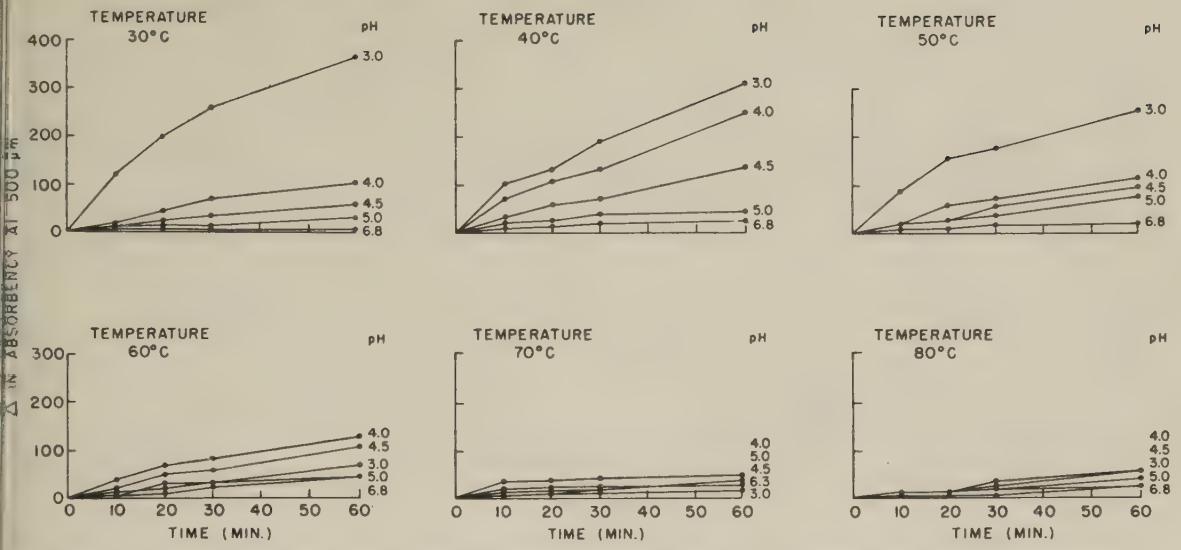


FIGURE 1.—Protein autolysis rates of whole herring homogenates held at various pH's and temperatures.

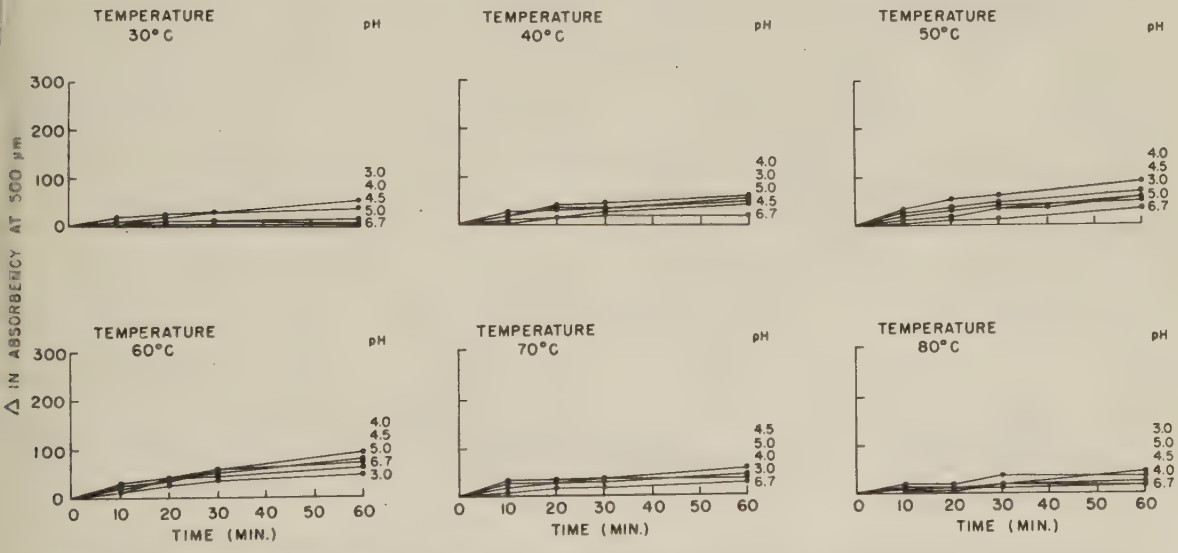


FIGURE 2.—Protein autolysis rates of eviscerated herring homogenates held at various pH's and temperatures.

are shown in Figure 5. The pattern is similar to that of whole hake, both in magnitude of activity and the effects of pH and temperature. Previous investigations in this laboratory (Dassow, Patashnik, and Koury, 1970) have shown that hake is often infected with the parasite, myxosporidian. The degree of this infestation is much greater in the outside than in the inside hake (Patashnik, personal communication, 1970). These investigators reported that infested hake autolyze rapidly during storage, making them unsuitable for processing into blocks or portions. No detailed study relating to parasites was made in this study, but the similar autolytic rates between whole and eviscerated outside hake shows that the main source of pro-

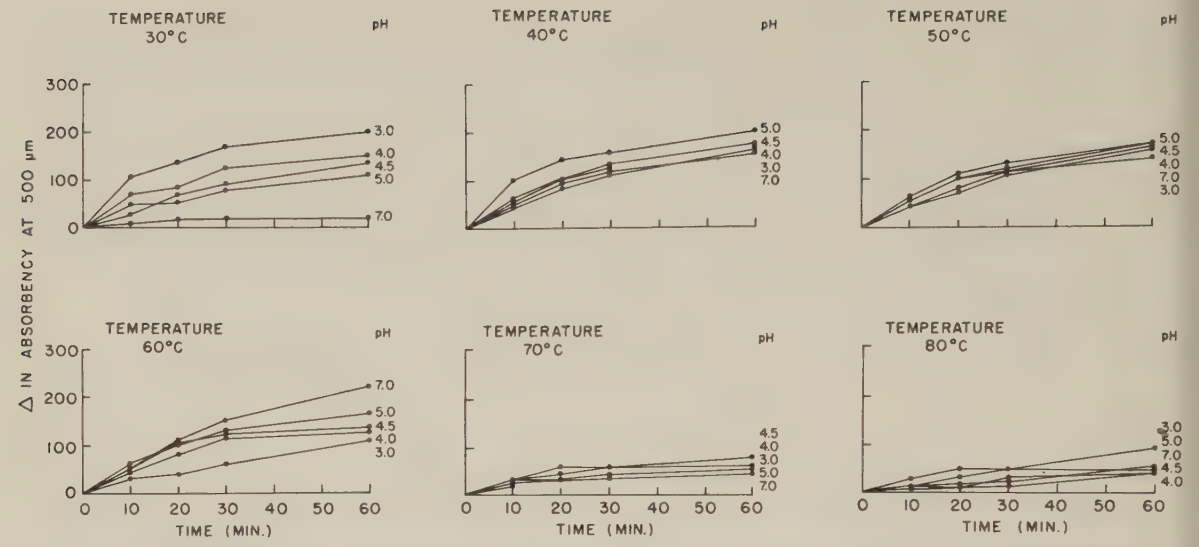


FIGURE 3.—Protein autolysis rates of whole hake (outside) homogenates held at various pH's and temperatures.

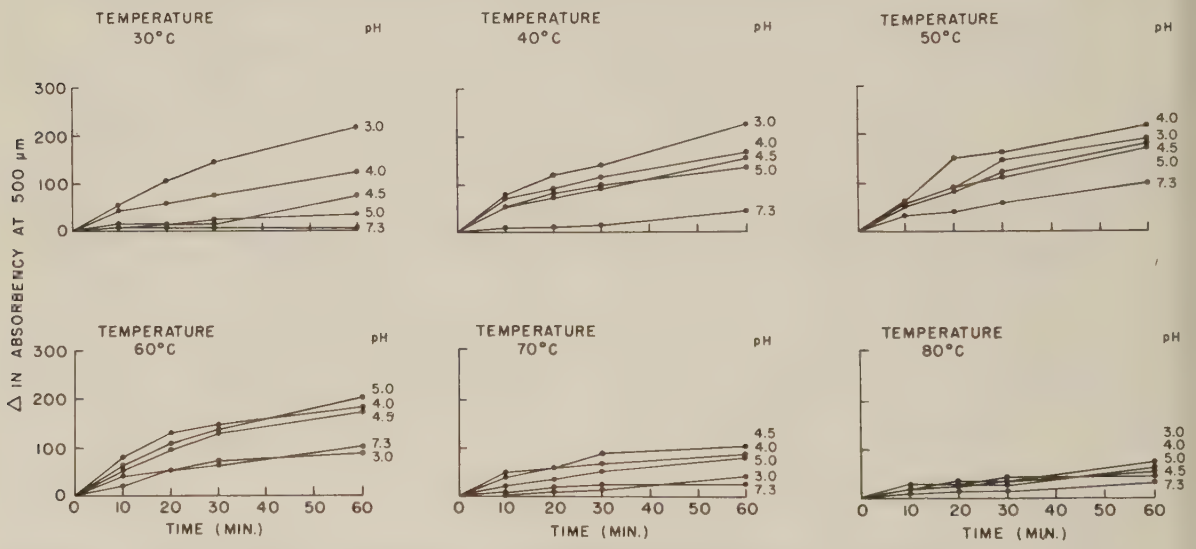


FIGURE 4.—Protein autolysis rates of whole hake (inside) homogenates held at various pH's and temperatures.

teolytic enzyme in the outside hake taken for this study resides in the tissue.

EFFECT OF AUTOLYTIC ACTIVITY ON YIELD OF FPC

MATERIALS AND METHODS

Whole inside hake were used throughout this experiment. For the preparation of FPC, whole hake was comminuted by passing through a Hobart grinder (equipped with a 1/8-inch plate). Aliquots of the comminuted fish were acidified with 0.1 M HCl to pH 5.5 and 4.5. The original pH of the fish was 6.9. The treated fish was allowed to autolyze at 50° C for 0, 20, 40, and 60 min. After each time interval, FPC was prepared by isopropanol (IPA) extraction as follows: The fish was successively extracted (4

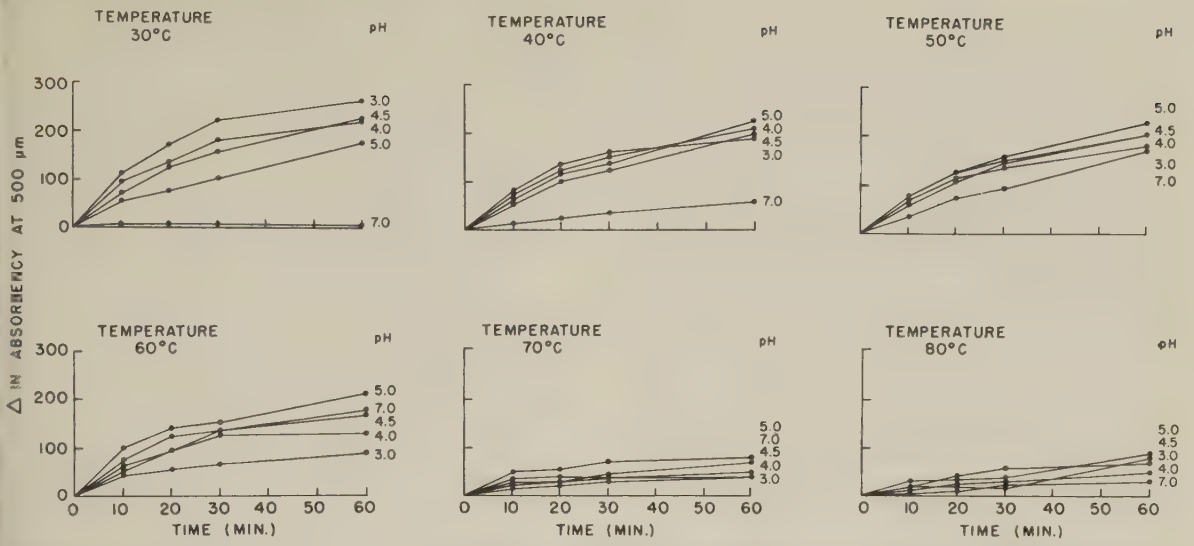


FIGURE 5.—Protein autolysis rates of eviscerated hake (inside) homogenates held at various pH's and temperatures.

times) with azeotropic IPA at a ratio of 2 parts IPA to 1 part fish. The first extraction was carried out at ambient temperature, and the final three extractions were carried aut at 70° C. Yields were calculated after drying the fish solids for 16 hr at 70° C at 25 inches of vacuum.

RESULTS AND DISCUSSION

The effect of autolytic activity on the subsequent yield of FPC is shown in Figure 6. It can be seen that while the acidified samples showed the greatest loss of yield with time of autolysis, the largest yield losses occurred during the first 20 min. The pH values, time, and temperature were arbitrarily chosen to simply demonstrate the effect of autolysis with respect to yield. They do, however, show a close correlation with the autolysis data shown in the previous experiment. For example, in referring to Figures 1 through 5, it can be seen that the rate of NPN formation is greatest during the first 20 min regardless of pH and temperature. Several investigators (Whaley, 1966; Sen, Sayanarayana Rao, Kadkol, Krishnaswamy, Venkata Rao, and Lahiry, 1969) have proposed acidifying comminuted fish prior to processing without taking into account the effect of protein losses due to autolysis. The combined experiments presented here clearly demonstrate the need to control temperature and pH, both before and during processing.

SUMMARY AND CONCLUSIONS

The above study shows that the endogenous proteolytic enzymes in fish hydrolyze the proteins into subunits that are not coagulable by

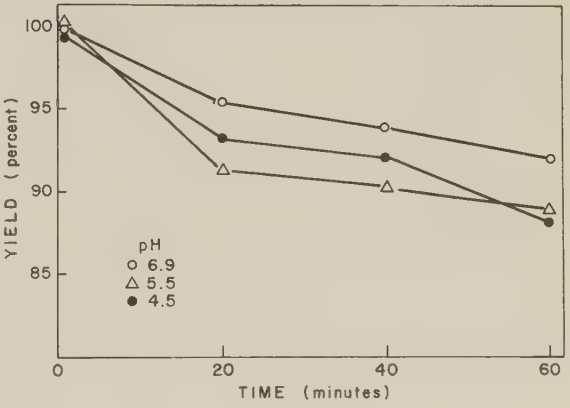


FIGURE 6.—Effect of protein autolysis on the yield of PFC made from inside hake. Autolysis was allowed to proceed for 0, 20, 40, and 60 min at 50° C prior to preparation of FPC.

the isopropanol concentration normally used in the preparation of FPC. The preparation of FPC made from autolyzing hake showed that the yield bore a close inverse relation to the degree of autolysis.

The autolysis rates in Pacific herring and hake were related to pH and temperature, the rates showing an increase with increasing temperature and a decreasing pH. Maximum activity was reached at about 50° C. Inactivation of the enzymic systems occurred when temperatures exceeded 70° C.

Since the economic success of any method that is used for the preparation of FPC is largely dependent on the yield of finished product obtained from a given amount of raw material, autolysis rates are a process parameter that should be closely controlled.

LITERATURE CITED

DAMBERGS, N.
1969. Isopropanol-water mixtures for the production of fish protein concentrate from Atlantic herring (*Clupea harengus*). J. Fish. Res. Bd. Can. 26(7): 1919-1926.

DASSOW, JOHN A., MAX PATASHNIK, AND BARBARA J. KOURY.
1970. Characteristics of Pacific hake (*Merluccius productus*) that effect its suitability for food. *In* Pacific hake, p. 127-136. U.S. Fish Wildl. Serv., Circ. 332.

DUBROW, DAVID L., NORMAN L. BROWN, E. R. PARISER, HARRY MILLER, JR., V. D. SIDWELL, AND MARY E. AMBROSE.
1971. Effect of ice storage on the chemical and nutritive properties of solvent-extracted whole fish—red hake, *Urophycis chuss*. Fish. Bull. 69 (1): 145-150.

DUBROW, DAVID, AND OLIVIA HAMMERLE.
1969. Holding raw fish (red hake) in isopropyl alcohol for FPC production. Food Technol. 23(2): 254-256.

KNOBL, GEORGE M., JR.
1967. The fish protein concentrate story. Food Technol. 21(8): 1108-1111.

LOWRY, OLIVER H., NIRA J. ROSEBROUGH, A. LEWIS FARR, AND ROSE J. RANDALL.
1951. Protein measurement with the folin phenol reagent. J. Biol. Chem. 193(1): 265-275.

SEN, D. P., T. S. SAYANARAYANA RAO, S. B. KADKOL, M. A. KRISHNASWAMY, S. VENKATA RAO, AND N. L. LAHIRY.
1969. Fish protein concentrate from Bombay-duck (*Harpoden nehereus*) fish: Effect of processing variables on the nutritional and organoleptic qualities. Food Technol. 23(5): 683-688.

SIEBERT, G.
1962. Enzymes of marine fish muscle and their role in fish spoilage. *In* Eirek Heen and Rudolf Kreuzer, Fish in nutrition, p. 80-82. Fishing News (Books) Ltd., London.

TING, CHAO-YUN, M. W. MONTGOMERY, AND A. F. ANGLEMEIER.
1968. Partial purification of salmon muscle cathepsins. J. Food Sci. 33(6): 617-620.

WHALEY, WILSON M.
1966. Production of fish proteins. U.S. Patent No. 3,252,962.

NOTES

EQUIPMENT FOR HOLDING AND RELEASING PENAEID SHRIMP DURING MARKING EXPERIMENTS[1]

Personnel of the National Marine Fisheries Service Biological Laboratory at Galveston, Texas, have conducted numerous mark-recapture experiments to obtain information on the movement, growth, and mortality of penaeid shrimp. These experiments were carried out under a variety of conditions at sea and in coastal bays. Several types of specialized equipment were developed to overcome problems of holding, handling, and releasing shrimp during the marking phase of these experiments. Some of this equipment has been described previously by Costello (1964). Holding tanks, a cooling unit, and two devices used to transport shrimp to the sea floor are described here.

Holding Facilities

A number of factors were considered in the design of tanks for holding shrimp. Construction materials had to be relatively light in weight, require little maintenance, and be nontoxic to shrimp. Provisions also were needed to permit rapid water exchange, minimize water turbulence within tanks, and control water temperature. The tank design in Figure 1 meets these needs and has proved successful for both sea- and land-based operations. It is constructed of light gray fiberglass with wood reinforcement and weighs about 114 kg (250 lb.). Advantages of the light color are that it reflects heat and makes shrimp easily visible in the tank. To permit rapid drainage or water exchange, a polyvinyl chloride (PVC) pipe, 7.6 cm (3 inches) in diameter, is molded into each end of the tank near the bottom. Filter screens, used to prevent loss of shrimp in outflowing water, have a large surface area to minimize clogging. A one-quarter section of PVC pipe, 7.6 cm (3 inches) in diameter, is molded to the top of the tank at each end as a splash rail to reduce spillage.

Five sets of guides in the tank support baffles that reduce water turbulence at sea and are used to separate groups of shrimp in a tank (Fig. 1). The baffles have a frame of aluminum flashing covered with sheets of patterned aluminum 0.063 cm (0.025 inch) thick.

During field use, a series of two to four tanks are linked to provide either recirculating water or continually flowing new water. The pump used depends on the volume of water required. Normally, we use a cast-iron pump powered by a 0.5-hp electric motor (110-220 v) that discharged 114 to 132 liters (30 to 35 gal) per min. As the water is discharged into the tanks, it passes through siphon filler-drain nozzles (Costello, 1964) which draw air into the circulation system and aerate the water. The aeration unit (Fig. 2), made of 1.9-cm (0.75-inch) pipe, may be attached temporarily at any convenient place on the tank. The amount of air that enters the water is regulated by valves in each air line.

Because it is difficult to keep shrimp alive when water temperatures exceed about 27° C (80° F), cooling units are used to lower and maintain temperatures in holding tanks. A cooling unit of our own design is shown in Figures 3 and 4. The casing consists of a PVC pipe, 25.4 cm (10 inches) inside diameter, 45.7 cm (18 inches) long, and 0.9 cm (0.37 inch), thick, and top and bottom pieces of PVC flat stock, 30.5 by 30.5 by 1.3 cm (12 by 12 inches by 0.5 inch) with circular grooves 0.6 cm (0.25 inch) deep. O-ring gaskets that fit the grooves prevent leakage of water. The refrigerant coil is made from 0.9-cm (0.37-inch) diameter stainless steel tubing, 9 m (30 ft) long. A thermostat sensor receptacle, inserted through the top

[1] Contribution No. 304, National Marine Fisheries Service Biological Laboratory, Galveston, Texas.

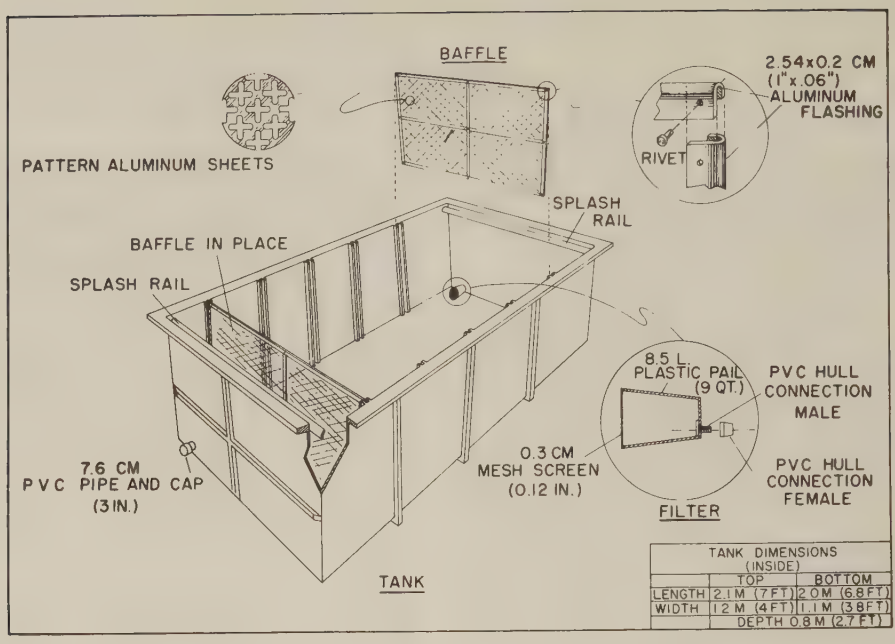


FIGURE 1.—The holding tank, baffles, and filters used in shrimp marking experiments.

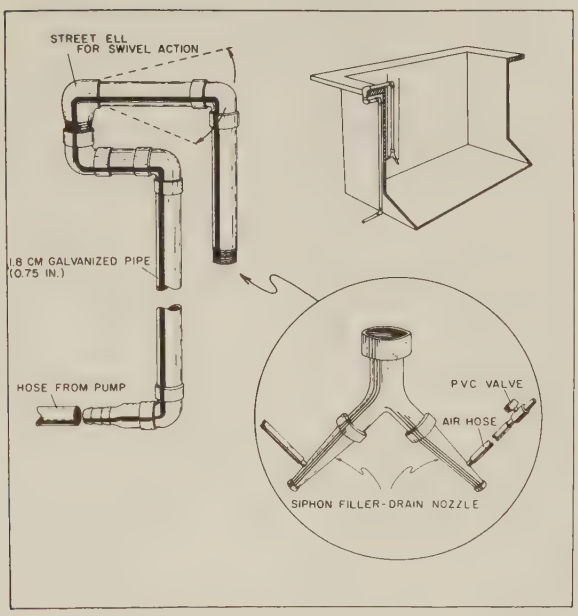


FIGURE 2.—Aeration unit and siphon filler-drain nozzle through which water enters tank.

plate of the cooling tank, consists of a piece of 0.6-cm (0.3-inch) diameter stainless steel tubing, 20.3 cm (8 inches) long, and is sealed at one end. The top of the chilling tank is reinforced by a 30.5 by 30.5 cm (12 by 12 inches) frame made from angle aluminum stock 3.8 by 3.8 by 0.6 cm (1.5 by 1.5 inches by 0.25 inch).

Two experiments were completed to determine the cooling capability of the unit. Water was recirculated through the chilling unit at rates of 114 to 132 liters (30 to 35 gal) per min, and thermographs recorded water and air temperatures (Fig. 5). The temperature attained after 24 hr was about 15.6° C (60° F) and was lower than that required for shrimp-marking procedures. Field observations have indicated that water temperatures can be maintained within 2° C (4° F) of desired levels, irrespective of fluctuations in air temperatures.

A table top with plastic pans 33.0 cm (13 inches) long, 38.1 cm (15 inches) wide, and 13.97 cm (5.5 inches) deep equipped for continuous water circulation (Fig. 6) slides over the lip of the holding tank and extends about 5 cm (2 inches) beyond the ends of the tank. When in

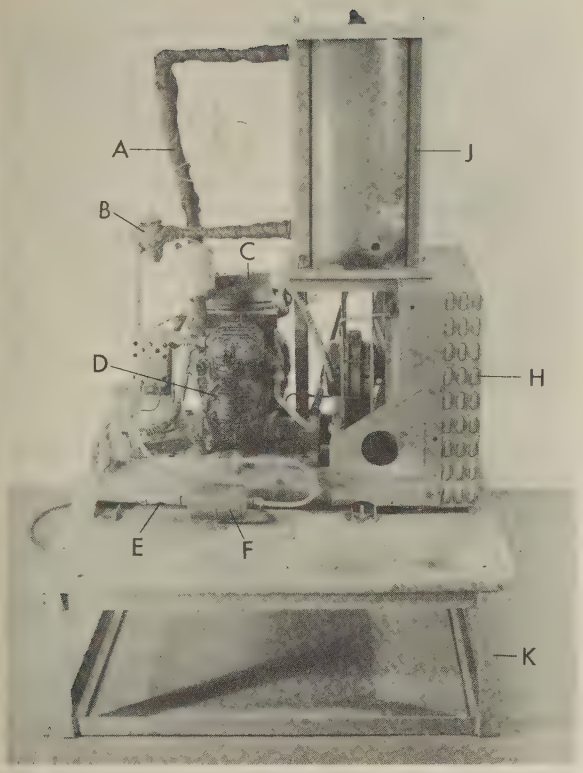


FIGURE 3.—One-hp single-phase compressor and condensing unit (12,000 BTU factory rated) attached to a PVC chilling tank and mounted on angle iron stand. A. vibration joint; B. expansion valve; C. thermostat control; D. compressor; E. sight glass; F. dryer; H. condensing unit; J. chilling tank; K. angle iron stand.

place, the table top serves as a work area for staining and tagging shrimp which are held in the pans.

Equipment for Releasing Shrimp

Three types of release devices have been developed to protect shrimp from exposure to predation during their return to the sea floor. Costello (1964) described a release box that is lowered to the bottom with a winch and opened by

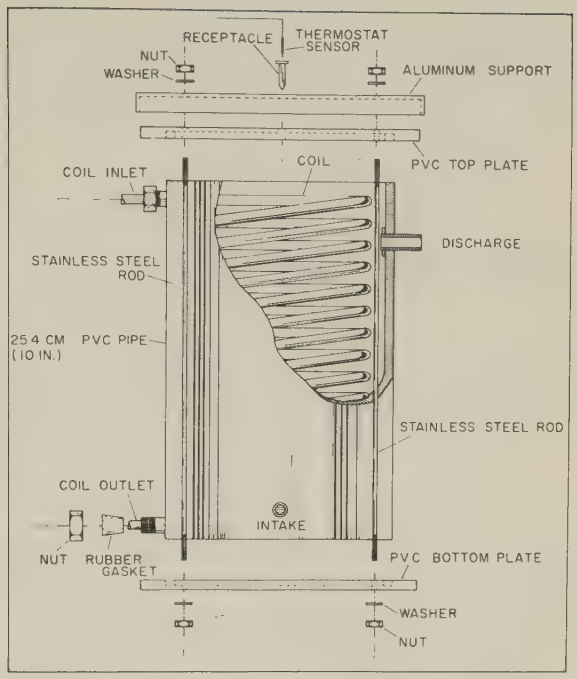


FIGURE 4.—Details of the chilling tank assembly.

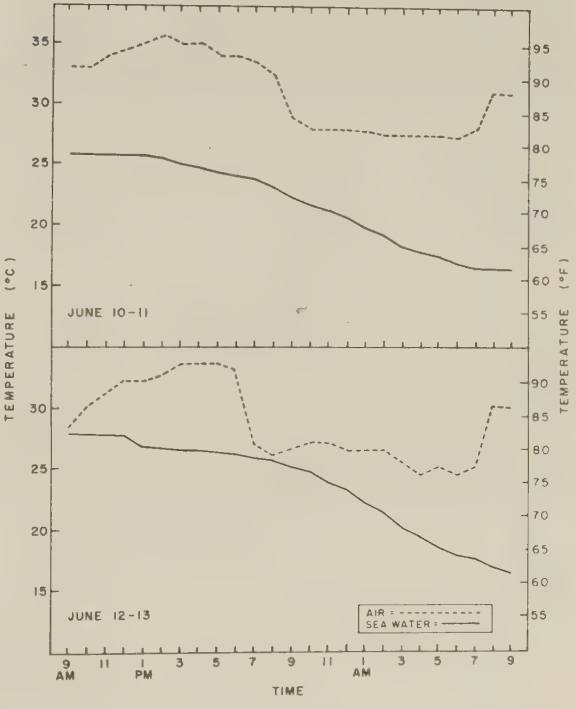


FIGURE 5.—Reduction of water temperatures in a 1,892-liter (500-gal) tank compared to surrounding air temperatures during trials with the chilling unit.

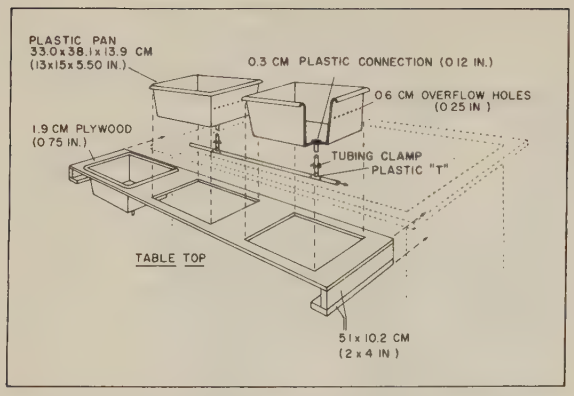


FIGURE 6.—Removable table top and holding pans equipped for continuous water circulation.

a messenger dropped down the cable. Use of this device is restricted to large vessels equipped with a winch, and requires that the vessel be stopped when shrimp are released. To circumvent these requirements, we designed an expendable release canister that can be put overboard while a vessel is underway and a release tube for use in shallow water.

The canister (Fig. 7) is constructed of high-impact styrene plastic formed into a hollow cylinder. Tabs on each of the styrene plastic end pieces have holes to accommodate retaining rods used in assembling the canister. Assembly and loading are accomplished in a cradle attached to the inner wall of a holding tank so that shrimp will remain submerged until the canister is ready to be put overboard. Slots in the canister allow it to fill with water.

A salt block, a rubber band, and a paper clip constitute the release mechanism. This mechanism is set by folding together the two ends of the styrene plastic sheet (thus forming a cylinder) and securing them with a rubber band. When ends A and B (see canister, Fig. 7) are folded, the paper clip is inside the canister with the attached rubber band inserted through a hole (end A) and a slot (end B). The salt block is then inserted in the loop formed by the rubber band, and the retaining rods are removed.

A cement weight (1.1 kg or 2.5 lb.) is attached and the canister is lowered to the water surface and released. When the salt block dissolves, tension in the canister wall pulls the rubber band from the slot (end B) and the canister disassembles, releasing the shrimp. Although never observed during the actual release of shrimp in offshore waters, this release devise was tested in shallow estuarine waters and in the laboratory. In all tests it performed as expected. The canister accommodates up to 100 shrimp that

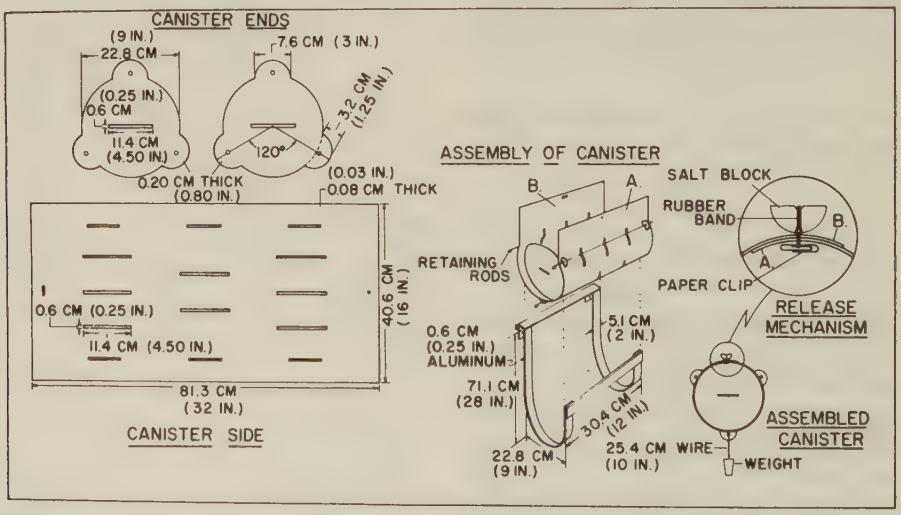


FIGURE 7.—Disposable release canister showing release mechanism, loading cradle, and method of assembly.

are released on the sea bottom within 5 to 15 min from the time the unit enters the water, depending on the size of the salt block.

The release tube (Fig. 8), intended for use in shallow water, consists of two telescoping aluminum pipes, each about 3 m (10 ft) long. To release shrimp, the outer pipe is lowered to the bottom and shrimp are poured from a pail into the funnel. After each pail of shrimp is poured into the unit, the apparatus is flushed with several pails of water to insure that shrimp do not remain in the tube. The pouring and flushing of one pail of shrimp usually take about 1 min.

The new equipment described herein and the improved techniques for staining and tagging described by Neal (1969) enabled us to hold, mark, and release large numbers of shrimp. We can now process between 1,500 and 3,000 shrimp per day, depending on the type of mark used.

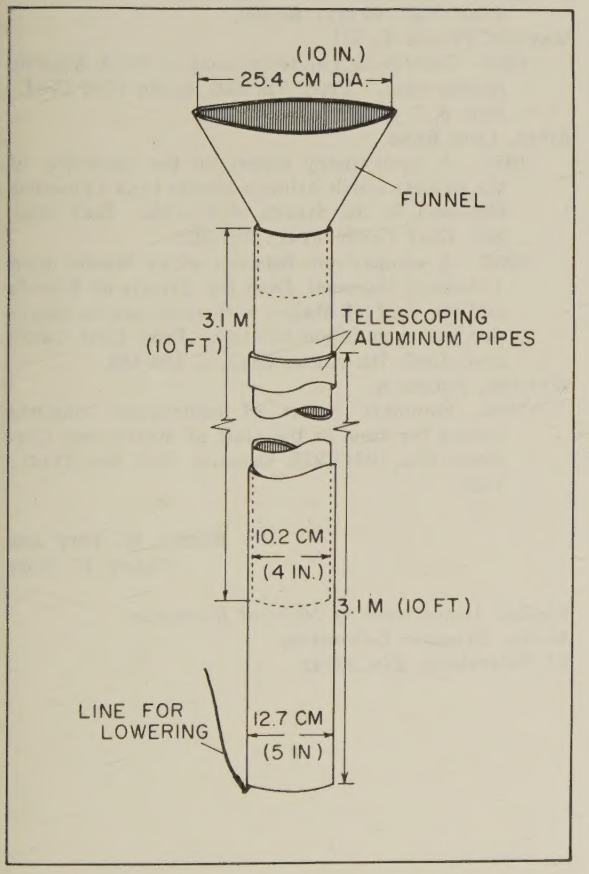


FIGURE 8.—Release tube used to place marked shrimp on the bottom.

Literature Cited

COSTELLO, T. J.
1964. Field techniques for staining-recapture experiments with commercial shrimp. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 484, 13 p.

NEAL, RICHARD A.
1969. Methods of marking shrimp. FAO (Food Agr. Organ. U.N.) Fish. Rep. 57, 3: 1149-1165.

DENNIS A. EMILIANI

National Marine Fisheries Service
Biological Laboratory
Galveston, Texas 77550

AN ADULT BLUEFIN TUNA, *Thunnus thynnus*, FROM A FLORIDA WEST COAST URBAN WATERWAY[1]

The bluefin tuna, *Thunnus thynnus* (Linnaeus), is a wide-ranging pelagic species occurring in most tropical and temperate seas (Gibbs and Collette, 1966: 119). In the Gulf of Mexico exploratory and commercial catches have been limited to the northern, western, and central parts, from waters beyond the continental shelf. The collection of a large adult from the Florida west coast represents a new record for the Florida shelf.

The specimen, a female, was captured by local fishermen with harpoons in a waterway at Hudson, Fla., (lat 28°21′24″ N, long 82°42′42″ W) on 10 May 1970. It weighed 239 kg (525 lb.), was 244 cm (96 inches) in fork length and 168 cm (66 inches) in girth, and appeared to be in healthy but lean condition, characteristic of post-spawning fish in May on the Bahama Banks (Rivas, 1955: 139).

Histological examination of gonadal tissue sectioned at 6 μ and stained with Harris hematoxylin and Eosin Y showed early and late atretic

[1] Contribution No. 154.

body formations, indicating recent spawning. The stomach contained a mussel, *Brachidontis recurvus* (Rafinesque), a piece of marl (no doubt ingested accidentally), and a digenetic trematode; gills and other tissues were free of parasites.

The fish had entered the waterway through a shallow navigation channel from the adjacent grass flats. The waterway, a network of channels cut through marl, consists of several 161 m by 15 m "fingers" branching from a 1370 m by 22 m central channel, with depths averaging less than 5 m at low tide. Surface salinity in the waterway, tested at a subsequent low tide, was 27.0 ‰; surface temperature in the adjacent Gulf was 26° C.

This occurrence, although admittedly irregular, may help to fill a gap in our emerging picture of the origin and distribution of Gulf of Mexico bluefin tuna stocks.

Bluefin tuna are taken from the Greater Antilles in spring, with substantial numbers of large adults being reported from the Windward Passage in April (Bullis, 1955: 6). During May they begin their dramatic migration through the Straits of Florida toward the summer feeding grounds (Rivas, 1954, 1955).

The occurrence of large bluefins at Grand Cayman and east of Cozumel in April (Bullis and Mather, 1956: 9) suggests that at least a component of these Caribbean stocks may undertake a similar northward movement through the Yucatan Straits and into the Gulf of Mexico. The occurrence of ripe or nearly ripe females in the Gulf in May and of small juveniles (less than 8 cm) in the northern Gulf in late May and early June (Mather, 1962: 5) implies that these stocks spawn in the Yucatan Straits or in the Gulf of Mexico proper. Our spent female on the Florida shelf could be from the Caribbean stock or from a stock wintering in the Gulf (Bullis, 1955: 13; Wathne, 1959: 16).

We are indebted to Gordon D. Marston, *St. Petersburg Times*, for informing us of the incident, to Bud and Marvin Mattix and others for allowing us to examine the fish and viscera, to Richard B. Roe for providing information on specimens collected during exploratory fishing by U.S. Fish and Wildlife Service vessels in the Gulf of Mexico and Caribbean, to Alice Gennette for preparing histological sections, and to Frank J. Mather, III for critically reviewing the manuscript.

Literature Cited

BULLIS, HARVEY R., JR.
1955. Preliminary report on exploratory long-line fishing for tuna in the Gulf of Mexico and the Caribbean Sea. Part I - Exploratory fishing by the *Oregon*. Commer. Fish. Rev. 17(10): 1-15.

BULLIS, HARVEY R., JR., AND F. J. MATHER, III.
1956. Tunas of the genus *Thunnus* of the northern Caribbean. Amer. Mus. Nov. 1765, 12 p.

GIBBS, ROBERT H., JR., AND BRUCE B. COLLETTE.
1966. Comparative anatomy and systematics of the tunas, genus *Thunnus*. U.S. Fish Wildl. Serv., Fish. Bull. 66(1): 65-130.

MATHER, FRANK J., III.
1962. Distribution and migration of North Atlantic bluefin tuna. Proc. 7th Int. Game Fish Conf. Pap. 6, 7 p.

RIVAS, LUIS RENE.
1954. A preliminary report on the spawning of the western north Atlantic bluefin tuna (*Thunnus thynnus*) in the Straits of Florida. Bull. Mar. Sci. Gulf Carib. 4(4): 302-322.
1955. A comparison between giant bluefin tuna (*Thunnus thynnus*) from the Straits of Florida and the Gulf of Maine, with reference to migration and population identity. Proc. Gulf Carib. Fish Inst., 7th Annu. Sess., p. 133-149.

WATHNE, FREDRICK.
1959. Summary report of exploratory long-line fishing for tuna in the Gulf of Mexico and Caribbean Sea, 1954-1957. Commer. Fish. Rev. 21(4): 1-26.

ROBERT W. TOPP AND
FRANK H. HOFF

Florida Department of Natural Resources
Marine Research Laboratory
St. Petersburg, Fla. 33731